13/Chap. 10

DESIGN STANDARDS

EMBANKMENT DAMS

NO. 13

CHAPTER 10

EMBANKMENT CONSTRUCTION

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE
DENVER, COLORADO

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Bureau of Reclamation
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Approved:

Chief, Geotechnical Engineering
and Geology Division

July 1, 1991
Date

(To be filled in by employee who files this change in the appropriate standard.)

The above change has been made in the Design Standards

Signature

Date

DESIGN STANDARDS

No. 13

EMBANKMENT DAMS

CHAPTER 10

Embankment Construction

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER OFFICE
DENVER, COLORADO

ACKNOWLEDGMENT

The U.S. Army Corps of Engineers manual, "Construction Control for Earth and Rockfill Dams," EM 1110-2-1911, dated January 1977 [1] was used extensively to develop this design standard. Additions have been made and passages edited to reflect current Bureau of Reclamation practice.

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10.1

INTRODUCTION

PURPOSE

.1 The purpose of this chapter is to present concepts that designers should consider in relation to construction of an embankment dam.

SCOPE

.2 This design standard covers construction concepts that are important considerations from the viewpoint of embankment designers to ensure that design assumptions, field conditions, and construction practices are compatible.

DEVIATION FROM STANDARDS

.3 Concepts presented in this design standard should be adhered to by designers of embankment dams within the Bureau of Reclamation. Rationale for deviation from the standard should be presented in technical documentation for the dam and should be approved by appropriate line supervisors and managers.

REVISIONS TO THE STANDARD

.4 After this design standard chapter has been used for a 1-year minimum trial period, it will be revised incorporating appropriate comments from document users. Subsequently, the standard will be revised periodically as dictated by changes in concepts and technology. Comments and/or suggested revisions should be sent to the Denver Office, attention D-3620.

APPLICABILITY

.5 The concepts presented herein apply to design and construction of earth and rockfill dams.

GENERAL DESIGN CONSIDERATIONS

DESIGN INVOLVEMENT

.6 The design of an earth or rockfill dam continues through construction and operation until it is proven the dam is operating as intended by the designers. Designer's must ensure that foundation conditions, embankment materials, and construction practices are as assumed during design. If these conditions are not compatible with design assumptions, the dam may not function as intended. In some cases, this may lead to serious economic loss, structural failure, and possibly loss of life. It is therefore imperative that the designers of a dam be intimately involved with the construction of that dam.

10.7

During construction, design engineers and geologists should frequently reassess design concepts and assumed conditions compared to actual conditions observed in the field. This involves frequent visits to the project to observe actual conditions and construction procedures.

Much additional information concerning characteristics of foundations and abutments is obtained during clearing, stripping, and required excavation, and may confirm or contradict design assumptions based on earlier geologic investigations. Operations in borrow areas and in required excavations also provide much data pertinent to characteristics of fill material and of excavated slopes. Weather and ground-water conditions during construction may significantly alter the water content of proposed fill material, or create seepage and/or hydraulic conditions, and may necessitate modifications in design.

Design evaluation must also include analyses of compaction control results. It may require reanalysis of stability conditions based on (1) results of laboratory tests on record samples and additional foundation samples, and (2) field observations of pore water pressures, settlements, and lateral displacements. A high degree of coordination between design and construction engineers is mandatory.

COORDINATION BETWEEN DESIGN AND CONSTRUCTION

.7 Involvement of designers during construction of the dam is difficult at times because design philosophy is often somewhat different than construction philosophy, even though both want a high quality job. Designers want to ensure absolute compatibility with design intent, which in many instances involves changes resulting in construction delays. The contractor is interested in maintaining schedules and making a profit. The construction administration staff is caught in the middle of this controversy. All parties are trying to perform a high quality job compatible with their best interest, however, this may be at odds with the interests of other parties.

Some of the stress can be reduced by clear concise specifications as well as clear concise instructions to contract administration personnel with respect to design assumptions and reasoning for designer requirements during construction. This information is usually conveyed by construction considerations. Because most of this information is valuable to the contractor as well, the current policy is to include construction considerations and the basis for various assumptions in applicable sections of the specifications. For example, geologic and engineering reasoning for specifying excavation to particular surfaces for the foundation of the dam should be included in the specification section on foundation excavating. The degree of confidence in the requirements should also be conveyed. With this type of information available to the contractor in the technical paragraphs of the specifications where they are applicable, it gives the contractor a clearer understanding of risk involved in various aspects of his bid and, therefore, a better opportunity for a more responsive bid resulting in less likelihood that claim situations will develop. It also removes the possibility of the contractor denying knowledge of information that was essential to preparation of his bid.

10.8

Information that is not needed by the contractor or inappropriate information for the contractor can be conveyed to contract administration staff by letter, memorandum, or meetings. It should be born in mind, however, that the contractor is privileged to any information regarding the contract should he desire. Sampling and testing frequency for various embankment zones might be an example of information that would be transmitted to the Project Construction Engineer (PCE) separate from the specifications.

Designers and geologists should schedule briefings with the PCE's staff prior to and during construction. If the PCE staff desires, briefings should also be held with the contractor's staff to discuss design requirements and answer questions so that all concerned have a clear understanding of design intent and requirements. The ultimate goal is to impart to both construction and contractor staff as clear an understanding as possible of requirements, reasoning, and uncertainties in the specifications. The philosophy being that a clear understanding of design requirements, intent, and reasoning will better motivate good construction, administration, and inspection; and result in a smoother running contract and ultimately a better product.

The designers and geologists, especially the Principal Designer (PD) and Principal Geologist (PG), must give considerable attention to personnel relations as well as to design problems. The PD should establish good rapport with the construction staff as early as possible during the design data phase of the project. This promotes better understanding of each others needs and fosters trust and free exchange of information. With this kind of relation between designers and constructors, misunderstandings can be avoided.

The Construction Liaison Engineer (CL) is the key person in promoting good relations between design and construction. The CL is the link between design and construction and the PD and PG should ensure that all dealings with the construction staff has CL involvement. Construction Liaison Engineers generally have a good construction background as well as a good understanding of design needs. They are an asset to both the design staff and construction staff because they can forge understanding between the two fields. The PD's and PG's should strive to take full advantage of this expertise in their dealings with project and regional offices.

FOUNDATION TREATMENT

FOUNDATION AND ABUTMENT TREATMENT

.8 Preparation of the foundation and abutments for an earth or rockfill dam is a most difficult and important phase of construction; the thoroughness with which it is done is reflected in the performance of the completed structure. It is often difficult, and sometimes impossible, to correct foundation and abutment deficiencies that show up after construction is well underway or has been completed. The primary purposes of foundation and abutment treatment are to (a) obtain positive control of underseepage, (b) prepare surfaces to achieve satisfactory contact with overlying compacted fill, and (c) minimize differential settlements and thereby prevent cracking in the fill.

10.9

The work is intended to ensure that (a) foundations and abutments are stripped to depths sufficient to remove soft, organic, fractured, weathered, or otherwise undesirable materials; (b) depressions and fractures in rock surfaces are cleaned and adequately filled; (c) rock surfaces are made relatively smooth and uniform by shaping and filling; (d) subsurface cavities and fractures are detected and grouted; and (e) cutoffs extend to suitably impervious materials.

During this phase of construction, close liaison must be maintained between construction and design personnel, as most discrepancies between design and field conditions occur in these portions of the work. Few dams are constructed without encountering some undesirable foundation conditions that were not discovered in exploration for design, such as zones of weathered or fractured rock, cavities, soft soil areas, abandoned pipes or drains, and ancient stream channels filled with sands and gravels. This is the reason inspection trenches are generally required beneath the impervious zone of a dam when cutoff trenches are not specified. These inspection trenches provide access for careful examination of the foundation along the entire length of the dam to ensure that undesirable foundation conditions are detected. Design Standard No. 13, Chapter 3 - *Foundation Surface Treatment* gives specific details on foundation treatment; Chapter 2 - *Embankment Design* gives specific information on cutoff trenches as well as a brief treatise on grouting with references to more detailed information; and Chapter 16 gives design information on thin cutoff walls.

DEWATERING AND UNWATERING

DEWATERING AND DRAINAGE OF EXCAVATED AREAS

.9 Inadequate control of ground-water seepage and surface drainage during construction can cause major problems in maintaining excavated slopes and foundation surfaces and in compacting fill on the foundation and adjacent to abutment slopes. For non-negotiated contracts, plans and specifications should normally contain detailed procedures for dewatering and other drainage control measures during construction. These systems should control seepage and hydrostatic uplift in excavations, and provide for collection and disposal of surface drainage and seepage into excavations. In order to properly design functioning systems, adequate, accurate field data must be collected. For negotiated contracts, the construction contractor generally designs the water control systems, but the data for design must be furnished in the specifications. Inspections and observations must be made to ensure that dewatering and drainage control systems are installed correctly and are functioning properly.

A. Surface Erosion. - Surface erosion may present problems on slopes cut in silts, fine sands, and lean clays. Eroded material will wash down and fill the excavation below the slope. The slope itself will be left deeply scoured and rutted, making it necessary for costly smoothing operations to be performed before fill can be placed against it. Figure 10.1 shows surface erosion on an unprotected excavation at Calamus Dam, Nebraska. The best way to minimize surface erosion of temporary excavation slopes is to minimize exposure time by backfilling as soon as possible. This often cannot be done, however, and it becomes necessary to take other measures. Grass cover on the slopes is a good means of preventing surface erosion if it can be readily established, and if the slopes are to remain exposed for a season or two. Other slope

10.9B

protection measures such as riprap or asphaltic treatment are rarely justified for construction slopes. Thus it is necessary to keep as much water off the slope as possible. Most slopes can withstand rain falling directly on them, with only minor sloughing. Perimeter ditches and/or dikes at the top of the slope are needed to carry surface waters away from the excavation if surface waters outside of the excavation would otherwise run into it. Ditches may be needed at several elevations along the excavation slopes to collect and drain surface waters.

B. Springs - Springs are often encountered in rock foundations and abutments. Where seepage rises up through rock fractures, the effect of placing impervious fill on the foundation is to create a mud hole, impossible to compact, with fill material piping out as it is placed. Where the water is under a low head and has a single point of issue, a standpipe can usually be installed. A corrugated metal pipe of a diameter depending upon the size of the spring is placed over the spring area, and a damp mixture of quick-setting cement, sand, and gravel is packed around the outside of the standpipe base. Earth is then compacted around the outside of the pipe, in conjunction with normal lift placement and compaction above the base. Water inside the standpipe is kept pumped down as an impervious seal is achieved outside the pipe and until enough pipe sections have been added to retain the head of water in the pipe. The pipe is then filled with vibrated concrete or grout, and construction of the fill continued upwards and across the top of the plugged pipe by conventional methods. The area should then be continuously examined for evidence of new springs which often appear after an old spring is plugged. The standpipe can be filled with gravel to prevent collapse with a grout pipe installed to the base of the gravel for grouting when the head of water is controlled. This procedure can also be used for springs on the abutments when the fill reaches the same elevation as the spring. While filling operations are progressing below the spring, a small pipe can be grouted into the source of seepage and discharged away from the fill as a temporary measure. If the springs are not localized in area, more extensive methods as described in paragraph .9.C may be required.

Fig. 10.1 - Calamus Dam, Nebraska - Erosion of Cutoff Trench Excavation, USBR, 1981

10.9C

C. Sumps and Ditches. - When an excavation such as a cutoff trench is extended to rock or to an impervious stratum, there will usually be some water seeping into the excavation and/or "wet spots" in the bottom of the excavation, even with deep wells or wellpoint systems in operation. Water seeping into the excavation from the upstream and downstream slopes of a long cutoff trench can usually be collected by excavating narrow longitudinal ditches or drainage trenches at the intersection of the slopes and the bottom of the excavation or by forming such trenches with sandbags, with sumps located as necessary for pumping the water out. If the bottom of the excavation does not dry out, trenches at the up and downstream limit of the impervious foundation should be tried prior to excavating any ditches within the impervious foundation. If the bottom of the excavation still will not dry out, smaller ditches can then be cut through the problem areas and sloped to drain to the side trenches.

To keep the bottom of the cutoff trench dry while placing backfill, the drainage ditch system can be filled with gravel so the system can continue to function even after being covered with earth. The gravel should be uniformly graded with a maximum size of 1.5 inches (4 cm) so that high pressures are not required to grout the drain. The volume of grout used in the drain should be measured and compared to the volume of grout required to fill the voids which can be computed. These gravel-filled ditches should constitute only a very small portion of the overall area being drained to preclude the necessity of later grouting large portions of the bottom of the cutoff trench containing gravel. Gravel should not be placed in gravel-filled ditches until any foundation cleanup using wash water has been completed. The surface of the gravel can be covered with a layer of heavy felt paper, burlap, non-woven geotextiles, or half-round pipe or plastic sheeting or by a layer of stiff concrete to prevent migration of fines from the fill material into the gravel drain. The ditches are blocked at each end of the excavation by concrete plugs, but with riser pipes from each sump to the surface. Water can then be pumped from one or more riser pipes as necessary, with the remaining riser pipes serving as vent pipes.

After the backfill is brought to a height that will counteract the hydraulic head, the gravel-filled ditches are grouted. Cement grout is introduced under gravity through one riser pipe, with the vent pipes serving as an escape for air and water in the gravel. When grout issues from the vent pipes, the vent pipes are shut off and a slight pressure is maintained in the system until the grout has set. Following grouting, normal fill operations can continue. If only one sump is used in the drainage system, a vent pipe must be installed at an appropriate location before backfilling starts.

Extreme care must be used in conjunction with sumps and ditches to ensure that the contact zone between the impervious zone and its foundation is not short circuited. Gravel-filled ditches or surface drains should never be allowed to traverse more than about one-third of the width of the impervious foundation. The distance between ditches or drains entering from opposite edges of the impervious zone should be at least two-thirds the width of the impervious zone. Ditches should be laid parallel to the dam axis to the extent possible.

Extreme care should be exercised to ensure that the grouting system used to seal the drains after their purpose is served is absolutely effective. Vent pipes/grout return pipes should not be spaced further than about 20- to 30-foot (6- to 9-m) centers so that grout return is guaranteed. A general rule is to space the vents no further apart than the amount of embankment covering the french drains at the time of grouting. The gravel ditch must be effectively sealed so that grout is contained within it and does not damage the surrounding fill. Grouting pressures must be controlled so that the fill is not jacked away from the foundation or hydro-fractured. Grout pressures should be that imposed by gravity or only slightly above. A positive factor of safety of grouting pressure at the elevation of the drainage ditch as compared to the effective pressure of the fill should be maintained. The grout mix should be as thick as possible, but still flow effectively through the gravel drain. It should have a water cement ratio by volume of no thinner than about 2 to 1.

Sumps and ditch systems are generally designed by the contractor during construction. Basic details of french drains and ditches should be shown on the drawings or described in the specifications. Specifications must provide for review and approval by the government/owner/engineer before the system is installed. The review must be sufficiently thorough so that the integrity of the foundation contact is absolutely ensured after the system is sealed by grout. Additionally, thorough inspection is required during installation, fill placement, and grouting of the system to ensure that requirements of the design are properly executed during construction. Figure 10.2 shows a drainage system successfully used at Ridgway Dam.

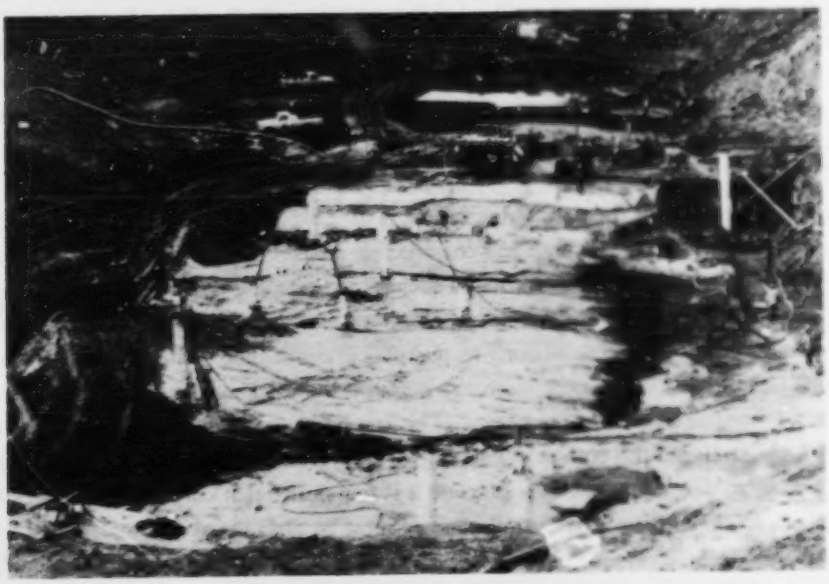

Fig. 10.2 - Ridgway Dam, Colorado - Sumps and Drains that were used for Drying the Impervious Foundation in the Cutoff Trench, USBR, 1982

10.9D

D. Impervious Barriers. - In many cases where a dewatering system is being used, a 4- to 5-ft (1.2- to 1.5-m) high impervious blanket placed at the toe of the slope will prevent the minor seepage flow that might otherwise occur and will thus provide a dry bottom. The blanket should be constructed of highly plastic soil and be of sufficient thickness to prevent seepage.

E. Dewatering. - When excavating the dam foundation below ground water through surficial deposits, deep wells or well points, or a combination of both, are usually required to control seepage into the excavation, especially where the excavation is through pervious to semi-pervious soils. Current policy is for these systems to be designed by Reclamation. The sump and ditch systems described previously for springs and local seepage are usually used to supplement the dewatering system and are generally contractor designed, but approved by Reclamation.

The dewatering system must be properly designed for site specific conditions. This requires a knowledge of geotechnical conditions at the site. Geotechnical members of design teams are most familiar with the collected information and therefore are the most logical people to design the dewatering system. The contractor, on the other hand, is not familiar with the geotechnical conditions and data when the bid is prepared and usually has only a relatively short time for preparation of the bid. It is unrealistic to expect an accurate bid on the dewatering system if he has to design it during bid preparation time frame. This requirement very often leads to expensive claims. Therefore, Reclamation has adopted the policy of requiring its own design staff to design most dewatering systems.

The design of wells and well-point systems is beyond the scope of this chapter. The designer should refer to Design Standard No. 13 - EMBANKMENT DAMS, Chapters No. 5 and 8 for general guidance on seepage and seepage control. Dewatering and Groundwater Control, Army TM 5-818-5 [2] and Seepage, Drainage, and Flownets by Cedergren [3] provide excellent guidance for design of dewatering systems. Bureau of Reclamation Guide Specification No. C-608, dated December 20, 1990, for dewatering should be used when preparing specifications for dewatering.

Installation and operation of the dewatering system is an extremely important inspection requirement and is a responsibility of both the design staff and construction staff. Potential problems can often be detected in early stages by visual observations of increased seepage flow, piping of material from the foundation or slopes, development of soft wet areas, uplift of excavated surfaces, lateral movements of slopes, or failure of piezometer water levels to drop sufficiently as pumping is continued. Water pumped from dewatering systems must be observed daily at the discharge outlet; if the discharge water is muddy or contains fine sand, fines are being pumped from the foundation. (This can be observed by obtaining a jar of the water and noting sediment settling to the bottom). Pumping of fines from the foundation can cause internal erosion channels (piping) to develop in soil deposits, and it is imperative that corrective measures be taken. Wells or wellpoints from which fines are being discharged must be abandoned and sealed, and replaced with wells having adequate filters. Piezometers should be installed with dewatering systems to monitor drawdown levels in the excavation area. Piezometers should be read daily and the readings plotted to enable

10.9E

continuous evaluation. Daily pumping records should also be kept and evaluated to determine the quantity of water removed by dewatering systems and sump systems. These records are valuable for detecting inadequate seepage control and in evaluating claims by the contractor of changed conditions with reference to the plans and specifications. A detailed description of various types of dewatering systems, installation procedures, and performance evaluation is given in Army TM-5-818-5 [2]. A sketch of a single-stage wellpoint dewatering system is shown on figure 10.3, and a combination multistage wellpoint and deep well dewatering system used at Calamus Dam is shown on figure 10.4.

Failure of a dewatering system can result in extremely serious problems, often requiring extensive and costly remedial work. To prevent failure of the dewatering system, all power sources should be backed by standby gas- or diesel-powered pumping or generating equipment and standby pumps should be available.

When excavations bottom in impervious material, unrelieved artesian pressures in underlying pervious strata can cause heaving of the excavation bottom. Should the impervious stratum rupture under these pressures, boils (violent emission of soil and water) will develop and cause loss of the underlying foundation material, resulting in extensive damage to the construction and possibly expensive modifications to the excavation.

Figure 10.5 shows sand boils that developed in a permanent toe trench at Lake Alice Dam in Nebraska. Although these boils are not under high hydrostatic head, they are a concern and illustrate what happens if seepage is not adequately controlled. Similar or more violent boils could develop on the bottom of an excavation from excessive artesian pressures in underlying strata. Failure of excavation slopes may also occur because of excessive artesian pressures.

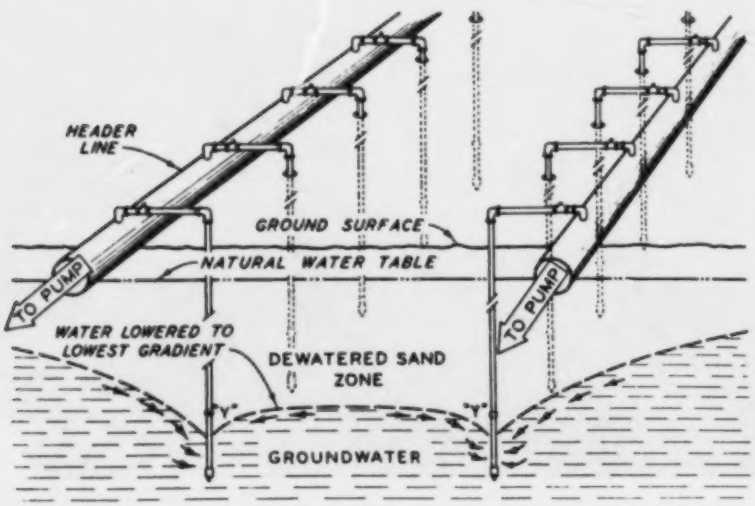

Fig. 10.3 - Sketch of a Single-stage Dewatering System [1]

10.9E

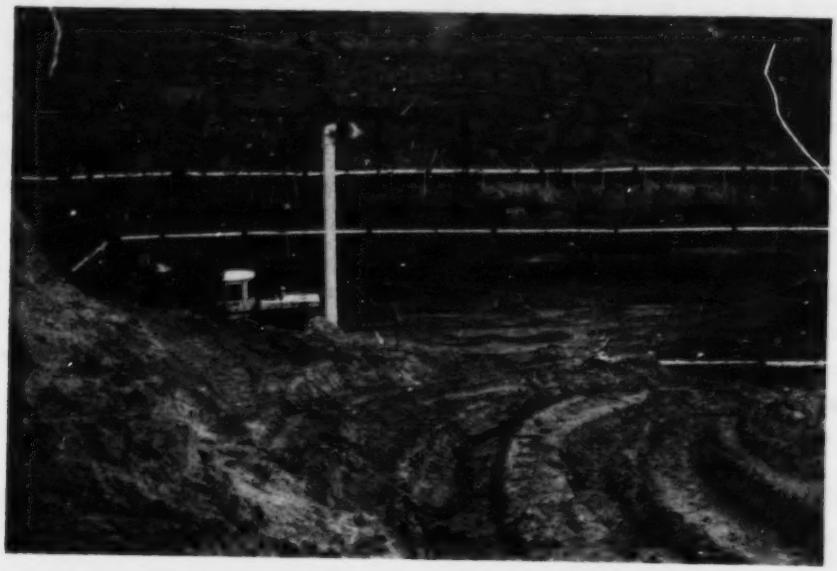

Fig. 10.4 - Calamus Dam, Nebraska - Multistage Wellpoint and Deep Well Dewatering System Used for Dewatering the Stilling Basin for the Outlet Works, USBR, 1982

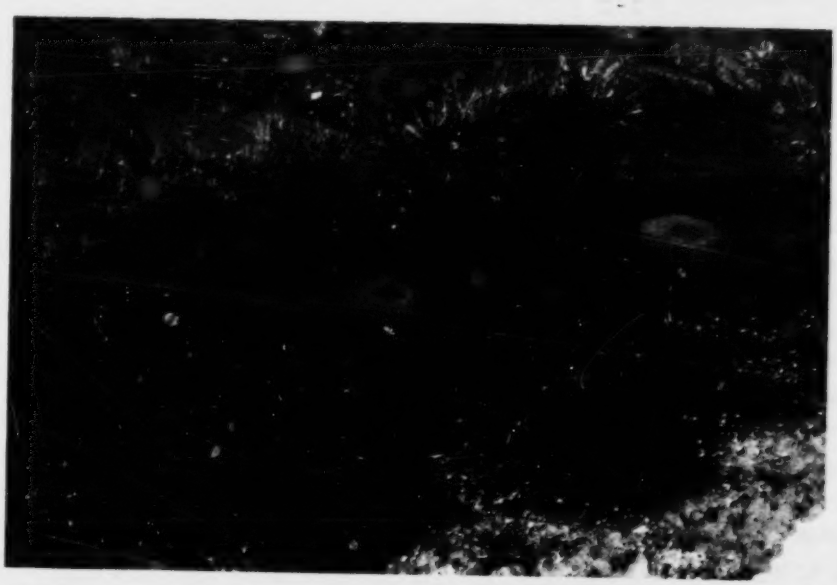

Fig. 10.5 - Lake Alice Dam, Nebraska - Sand Boils in a Toe Trench Downstream of the Embankment, USBR, 1982

F. Other Seepage Control Measures. - Other means of stabilizing excavation slopes and preventing seepage from entering an excavation, such as electro-osmosis, freezing, sheet piling, and grouting, have all been used for structure excavations. These methods are not economically feasible for extensive foundation excavations for dams, but might be used in more concentrated structure excavations where conventional dewatering methods are not suitable for various reasons.

BORROW AREAS AND QUARRIES

EARTHFILL - EXCAVATING, HANDLING, AND HAULING EQUIPMENT

.10 Over the past several decades, significant improvements have been made in earth-moving equipment at an increasing rate and there is no indication that this trend will slow down. While the basic types of equipment have remained virtually the same; speed, power, and capacity have continuously increased. Some of the basic principles of the more common units are discussed in the following paragraphs.

A. Excavation Equipment

1. Unsubmerged Borrow Areas. - Excavation is usually accomplished with front-end loaders, power shovels, draglines, scrapers, wheel excavators, or side-delivery loaders. Each offers certain advantages and each has certain disadvantages; therefore, several types of excavators are frequently used on the same job. Figure 10.6 shows a front-end loader used at New Waddell Dam.

2. Submerged Borrow Areas. - Although rarely used, dredging may be employed to move material from borrow areas to the damsite. Dredges are particularly suitable for use when large quantities of material are to be obtained from borrow areas submerged in rivers, lakes, etc. The two basic types of dredges are the bucket dredge and hydraulic dredge. Bucket dredges have a common limitation: the discharge is alongside the place of excavation. They can best be used for localized dredging or where the borrow area is so located that the material can be economically transported by trucks or barges to the site. All hydraulic dredges have a centrifugal pump and a suction line through which the pump is supplied with material. They differ in the means used to loosen and pick up material. An advantage of hydraulic dredges is that they can transport material without rehandling for almost unlimited distances with the aid of booster pumps. This feature is particularly desirable in constructing temporary dikes, and possibly permanent structures, by the hydraulic fill method.

10.10B

B. Hauling, Handling, and Separating Equipment. - When scrapers (or certain types of dredging procedures) are used to excavate borrow material, additional hauling and handling equipment may not be required. When other types of excavation equipment are used, hauling and handling equipment are required. Regardless of the type of excavation equipment used, the borrow material may require separation according to size or soil type. Some of the equipment used for hauling, handling, and separating borrow materials is discussed in the following paragraphs.

1. Trucks. - Trucks of many types are used to transport embankment material from the borrow pit to the dam, generally with capacities up to 50 tons being commonplace. Bottom dump trucks (belly dumps) have capacities of 100 to 120 tons. Trucks can be categorized according to method of unloading as bottom dump, end dump, or side dump. Figure 10.6 shows an end dump truck used at New Waddell Dam and Figure 10.10 shows a bottom dump on the same job.

2. Belt Conveyors. - Belt conveyors are used to transport material from the borrow area to the damsite when very large quantities of material must be moved under difficult conditions. Belt conveyors are most suitable for moving large quantities of material over very rough terrain where there are large differences in elevation between borrow pits and the dam, and where the costs of building and maintaining haul roads would be high. Conveyor systems are adaptable to different types of automated processing procedures such as screening plants, crushing plants, blending operations, water addition, etc. Transfer points (where the material is transferred from one belt to another) are usually required. Automatic facilities for loading trucks at the terminal points can be easily provided, or sometimes the material can be dumped directly from the belt onto the embankment, spread with dozers or graders, and compacted. Depending upon material type, segregation could be a serious problem, especially if the materials are moved a significant distance by the spreading equipment.

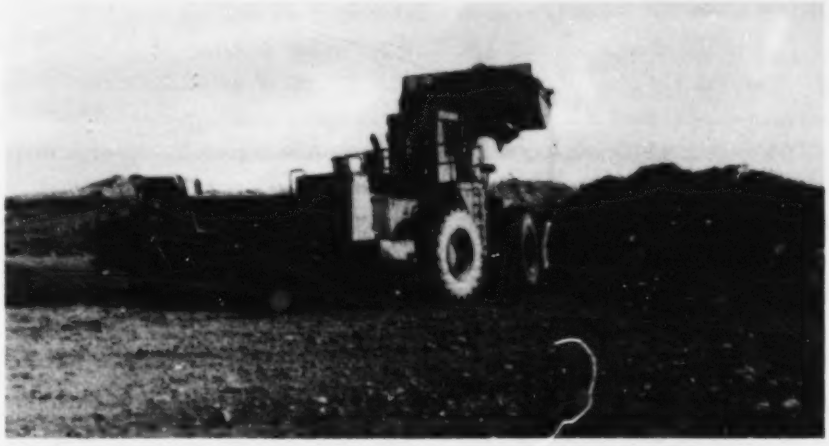

Fig. 10.6 - New Waddell Dam, Arizona - 11 yd^3 (9 m^3) Front-End Loader Loading a 30-Ton End Dump Truck with Alluvium Containing Sand, Gravel, Cobbles, and Boulders that will be Processed into Filter and Drain Material, USBR, 1990

10.10C

3. Separation Plants. - Separation or screening plants are employed where it is desired to separate different particle sizes of a material. Generally, the purpose is to remove oversize rocks or cobbles to facilitate compaction or to remove fines from filter materials. There are four principal types of screening plants:

- Horizontal or Sloping Stationary Screens. - Screens retain the coarser particles and allow the finer material to drop through by gravity.
- Vibrating Screens. - Screening separation process speeded by vibration.
- Rotating Trommels. - Rotating cylinders of perforated metal or screen.
- Wobblers (or Rotating Cams). - Rotating action of the cams causes the fines to fall through and the rocks to discharge over the front end.

Various plants have capacities ranging from 100 to 2,000 yd^3/h (75 to 1530 m^3/h), but most plants process 300 to 500 yd^3/h (230 to 380 m^3/h). Wet materials having appreciable clay content are the most difficult to process, because the clay tends to clog screen openings.

C. Borrow Area Operation

1. Plans for Development. - Specifications should require the contractor to submit detailed plans prior to construction for the development of borrow areas and quarries. These plans should be carefully reviewed prior to approval, and then be rigidly followed during construction.

2. Inspection. - Inspection of borrow pits is a function of the project office field staff, but the designer should be aware of their responsibilities. Inspection of borrow pits includes observing and recording all earthwork operations performed in the borrow pit prior to dumping the material on the embankment. The borrow pit inspector should observe areas excavated, depth of cuts, and adequacy of contractor equipment for the tasks at hand. The inspector should inform the chief inspector of conditions that deviate from the plans and specifications, so that corrective action can be taken if necessary. These deviations include:

- Borrow materials are different from those expected to be obtained in the borrow area.
- Borrow excavation operations are not producing the desired blend or type of material required.
- Borrow materials are too wet or too dry for proper compaction. During excavation and processing, the inspector should observe all adjustments made to the water content of the material. If separation or blending is required, the inspector should perform tests to ensure that the soil type and/or gradation of the processed material meets the specifications.

10.10C

3. Water Content Control. - Water content changes occur in the borrow pit because of rain, evaporation, and borrow area operations. However, specifications should require the contractor to have the water content of the excavated materials as close as possible to the desired water content prior to delivery on the embankment.

a. Dry Soils -

• For most clays it is not desirable to add more than 1 to 2 percent water on the fill. In arid regions the average natural water content of soils in borrow areas may be 10 to 15 percent below the desired value for compaction. Under such conditions, irrigation of borrow areas results in more uniform moisture distribution, while also being the most economical method of adding water. Borrow areas are frequently wetted to depths of 5 to 15 feet (1.5 to 4.5 m) by surface irrigation, and in some cases even more.

• Borrow pits are irrigated by ponding water on the surface with low dikes or with a pressure sprinkler system. Irrigation by ponding is most suitable in low-lying flat areas and for low permeability soils for which long periods of wetting are needed. While sprinkling can be done on low, flat areas, it is especially advantageous on sloping ground and in large borrow areas where only relatively shallow wetting is needed. In some borrow areas, it has been found desirable not to strip the top soil before irrigating, because the stripping operation tends to seal the natural holes and cracks in the ground surface that allow water to penetrate. On the other hand, in other borrow areas, ripping of tight surface layers has proven effective in speeding up the wetting process. When sprinkling is used on hillside borrow, it is often desirable to employ contour plowing to prevent surface runoff. Good judgment should be used in prewetting steep hillside borrow so that slides are not induced. The length of time required for wetting may vary from a few days to several months, depending on the permeability of the soil and the depth to which moistening is desired. After irrigation, a curing period is desirable to allow the added water to be absorbed uniformly by the soil. The time needed and the best method to use can be determined by experimentation with test areas during exploration or the early stages of construction.

• In some cases where general borrow pit irrigation is impossible or not satisfactory, supplemental water can be added by sprinkling the face of a shovel excavation. With this procedure, the water is mixed into the soil by the shovel dipper and blends with the loosely excavated soil as it is being hauled, dumped and spread. If the soil is being processed through a screening plant to remove oversize cobbles, a considerable quantity of water can be blended into the soil by sprinkling within the plant.

b. Wet Soils -

• It is generally easier to add water to dry soil than to reduce the water content of wet soil. The difficulty in lowering the water content of a soil deposit depends on the permeability of the deposit and on the amount and type of rainfall during construction. The rainfall pattern is important; for example, infrequent cloudbursts are less harmful than the same amount of precipitation falling as rain over a longer period of time. It is practically impossible to dry out borrow material to any extent without excessive work and cost unless there is a dry season of sufficient length to accomplish this.

• If the construction season is not excessively rainy, the first step toward drying out or maintaining the in situ water content of borrow material is to provide surface drainage in the borrow area. This is done by cutting ditches in the borrow area and by sloping surfaces to drain these ditches. This will minimize absorption of subsequent rainfall. Wet soils can sometimes be dried by ripping, plowing, or disking, thus aerating the soils to a depth of several inches (centimeters). In addition to climatic conditions, the time required for drying depends on the soil permeability and the depth to which the soil can be aerated. This procedure is repeated after removal of the dried soil layers by elevating graders or scrapers. This is a relatively dependable method for silty and sandy soils, but a very difficult one for clays. In dry climates, if the water content of high plasticity clays is lowered by aeration, the clay tends to dry into hard dry chunks that are difficult to process. In some sandy and silty soils, open ditches in a borrow area with a high water table will drain off some excess water and lower the water table.

• During the construction of Dorena Dam (Oregon) by the U.S. Army Corps of Engineers [1], disking of the borrow areas did not break up and mix the clay material enough to obtain uniform moisture conditions. This problem was solved by using a heavy rotary pulverizer pulled by a crawler tractor after the disking. Shortly after being pulverized, the material was at or near placement moisture, was easy to load, and was in excellent condition for compaction.

• In very wet climates, it may be possible only to prevent the material from getting any wetter during construction. This is done by providing surface drainage in the borrow areas and by using excavation equipment that minimizes the opportunity for the borrow material to soak up additional water. Excavation with power shovels on a vertical face is an example of this method.

10.10C

4. Blending Soil Layers with Excavating Equipment. - Blending two or more soil types may be required where different soil strata are present in borrow areas or required excavation. Reasons for blending soils are (a) to obtain borrow materials having acceptable characteristics for a particular embankment zone and (b) to use borrow materials so stratified in situ that it would not be feasible to load and place material from individual soil strata.

Where materials to be blended occur as horizontal strata, shovels, draglines, wheel excavators, or in some cases, scrapers have been used to blend them during excavation. Excavation with a power shove on a vertical cut will blend the materials. Where more extensive mixing is required, it can be achieved by running the open bucket through the mixture several times before loading. Construction control in this case will require maintaining the height of cut necessary to obtain the desired proportions of each type of material and to ensure that the materials are blended thoroughly.

Blending of different materials from different sources can be accomplished by stockpiling one layer fro each source upon the other so that excavation can be made through the two materials as in a stratifie natural deposit. However, this procedure is expensive and is seldom used.

Scrapers have been used to mix stratified deposits by developing the excavation in such a way that the scraper is loaded on an incline, either uphill or downhill, cutting across several horizontal strata of different materials; however, mixing by this method is not as effective as use of a shovel, dragline, or wheel excavator. Loading uphill with a scraper is more effective than downhill. However, the contractor may be difficult to convince because the former method requires more assist equipment. This extra effort results in larger, more compact loads.

5. Selection of Materials Intended for Different Embankment Zones. - The embankment or borro pit inspector should ensure that materials intended for a certain embankment zone are within specification limits. Selection of materials will, to a large extent, have been accomplished on the basis design studies; that is, borrow areas for the various zones will have been specified by the designers. Design studies should have disclosed the nature of the materials and the expected ranges of variation. Field personnel should review results of all investigations and become familiar with acceptable materia The inspector should be able to identify these materials visually and with a minimum of index tests.

The use of proper equipment by the contractor will also aid in preventing undesirable mixing of soil types. For instance, thicker stratified deposits of distinct soil types with fairly large areal extent may be kept separate by excavating with a scraper because scrapers excavate by cutting relatively thin strips of soil, thereby avoiding mixing of strata. These stratifications are very difficult to separate. A scraper wi not work on thinly stratified deposits. They should probably be blended. Screening plants are sometimes employed to obtain required gradations. Although screening of natural materials for major embankment volumes is an expensive process it may not be excessively so when compared with the benefits. The use of screening plants may avoid major placing problems, allow steeper embankment slopes, and a lesser volume of material. Screening is most often used in connection with filter materials.

The design staff should provide exploratory and laboratory information on borrow area material within the specifications. They should convey the basis for selecting various borrow areas for specific embankment zones as well as their confidence in volume and quality of the material for its intended use in the specifications. If zones will be encountered within a borrow area that will not meet requirements for material from that borrow area, this should also be noted in the specifications.

Materials of possible short supply should be noted in the specifications so that they can be conserved.

6. Oversized Materials. - The maximum diameter of stone or cobble allowed in compacted fill is generally limited to about 75 percent of the thickness of the compacted layer. Where a high percentage of oversized cobbles or stones are present, oversize material removed may be used in the outer portions of the dam. Oversize materials can be removed on the fill surface by hand labor or by special rakes mounted on tractors, or they can be screened out in the borrow areas. Removal of oversized rock is generally more efficiently accomplished in the borrow areas where rock separation plants are usually employed for this purpose. The exception to this is impervious fill. It is difficult to process oversize rock out of impervious fill as well as expensive. All other methods should be attempted first. Hand picking and rock raking on the fill generally work as well as processing in the borrow in impervious zones. Processing methods are discussed further in paragraph .10.D of this section.

7. Stockpiling. - When the excavation of fill material from borrow sources, including required excavation, progresses at a faster rate than its placement in the embankment, the material can be stockpiled near locations where it is to be used. This involves expensive rehandling and is generally done only on large projects where borrow is to be used from an excavation made prior to embankment construction, where borrow areas will be flooded during construction, or when material must be stockpiled close at hand for rapid construction of a closure section. Unless stockpiling is a specified item, its use is at the expense of the contractor. Stockpiling may also be useful where borrow must be transported over long distances and moved by belt conveyors or other means at the site. Filter materials are often stockpiled when it is necessary to obtain such materials from commercial sources or to manufacture them on the site. Care should be taken in stockpiling filter materials to avoid segregation, contamination, and particle breakage. In dumping filter material, drop heights should be kept to a minimum. The filter material stockpile should be located well away from other types of material, and the operation of heavy equipment over material that is to be subsequently used as a filter should be avoided. The area should be sloped such that water drains away from the stockpile. Gradation tests should be performed on samples of filter material from a number of locations in the stockpile as well as after it has been placed in the embankment to ensure that specifications are met. Because of the difficulty in sampling stockpile material, the results should be analyzed over a period of time to establish a composite evaluation. For any type of material stockpiled, the importance of controlling stockpile quality should be emphasized, particularly if another contractor will ultimately use the stockpile.

10.10D

8. Cold Weather Operations. - Borrow area operations can often continue into freezing weather without loss of quality of embankment fill. Except in extremely cold climates, frost penetration of in situ fine-grained soils is a slow process, and the soils will not become frozen if borrow operations are continuous. Material satisfactory for fill placement can be obtained if the in situ water contents do not require adjustment on the fill. Sands and gravels can generally be excavated and handled effectively even under very low temperatures, but the addition of water on the fill for compaction may present problems. Borrow excavation in cold weather is usually limited by fill placement requirements, but in any case should be limited to special situations and then used only with considerable caution.

D. Quarries and Rock Excavations. - Experienced geologists, engineers, and blasting experts can rely on their knowledge acquired from previous quarries to develop drilling and blasting plans that will optimize the quarryrock product. However, even experienced geologists and engineers may have difficulty predicting how rock obtained from a quarry or excavation will break down during and after blasting. The most frequent trouble occurs when the quarried material either contains more quarry fines and dust, or more oversized material, than was anticipated in the design. It has sometimes been necessary to make major design changes because rock behavior or breakdown was contrary to that anticipated by the designers.

1. Loading Equipment. - Front-end loaders are used almost exclusively today for loading trucks or other vehicles in rock excavations or quarries. Power shovels are used occasionally; large front-end loaders have gained prominence because of the advent of more powerful units with large capacity buckets. In a high face (deep) quarry, specifications should provide for the walls and face to be carefully scaled and cleaned after each shot to prevent rockfall accidents.

The power shovel, either electric or diesel, is still sometimes preferred for loading directly from the muck pile, although front-end loaders are used more often. The power shovel is sometimes desired because of its large capacity, its powerful bite, and its efficiency in getting the load from the bucket to the carrier.

Front-end loaders are used almost exclusively to load processed material from stockpiles. A front-end loader may be either tracked (crawler) or rubber-tired. The crawler type was often used in the past, but the four-wheel-drive rubber-tired types have recently become popular. Although the rubber-tired loader lacks the traction of the crawler loader, it is faster and usually has sufficient traction on most surfaces to load a full bucket efficiently.

For riprap quarries, track front-end loaders equipped with slotted rock buckets are often the preferred loading equipment. Shaking the rock in the bucket allows the smaller rock and fines to separate; this is an effective method in processing riprap and is often all that is necessary.

2. Hauling Equipment. - Trucks are generally used as prime movers of rock fill. The three basic truck types are the end dump, the bottom dump, and the side dump. Side dumps are rarely used for the construction of compacted rockfill dams; they are more useful for building out the edges of fills. Bottom dumps are more frequently used, but they have definite limitation; they are somewhat unwieldy, and oversize rock has a tendency to become trapped in their discharge gates, requiring bulldozers to push them off the rock, thus losing time and disrupting the hauling schedule. End-dump trucks are probably the most used vehicles for rock hauling because of their speed, mobility, and generally lower initial cost to the contractor. End dumps vary in size from the light "dump truck" to semitrailer types with capacities in excess of 100 yd^3 (75 m^3). Because in most cases, hauling from rock excavations and quarries is "off-the-road" hauling, these trucks are not subject to size and weight limitations imposed upon carriers that travel on public highways, thus allowing the large capacities.

3. Processing Equipment. - When it is impossible to obtain specified sizes or gradations of rock by blasting, it becomes necessary to process the blasted rock. This may involve removal of oversize or undersize material (fines) from the blasted rock or obtaining a specific size range for use in particular zones of the embankment. If the use of a processing plant is necessary, the need for stockpiling of filter zone materials to ensure a supply of properly graded fines during the rainy season when screens tend to clog up should also be investigated. There are several types of separation or processing plants; the one used depends on the end product desired. Figure 10.7 shows the processing plant used to produce filter and drain material at Reclamation's New Waddell Dam. This plant produced material from an alluvial borrow area, but equipment used in a rock quarry would be similar. Some of the more common components are briefly discussed in the following paragraphs.

- Grizzlies - The grizzly is probably the most commonly used rock separating device. The grizzly is used only for separating oversize rock from material. In many cases this is all that is needed to obtain the gradation specified. A grizzly is a grating made of heavy bars, usually built on a slope, across which the material to be processed is passed. The bars are wider at the top than at the bottom to keep the openings between bars from being clogged by particles caught part way through. The grizzly is often constructed with a sloping vibrating screen or with rotating cams (grizzle wobbler) so that oversize material is dumped over the end while the sized material passes through. Although there are many ways to construct a grizzly, all employ some type of heavy grating.

- Trommel - A trommel is a more sophisticated separating device, consisting of a rotating cylinder of perforated sheet metal or wire screen. It, too, is used for eliminating fairly large-sized material, but it can also separate the remaining material into several size fractions. The trommel is open at one or both ends, with the axis of the cylinder being horizontal or slightly inclined so that the material is advanced by the rotation of the cylinder. The perforations in the sheet metal or the size of openings in the screen can be varied to obtain more than one fractional size. As the raw material is fed into the rotating cylinder, the oversize material moves on through and is discharged at the other end, while each of the fractional sizes passes through its respective opening, usually being caught in hoppers or transported to stockpiles by conveyor belts.

10.10E

• Shaking or Vibrating Screen - This device is generally used for sizing. It consists of a metal screen, or screens with desired opening sizes, mounted either horizontally or inclined on a rigid frame and given either a reciprocating motion (in the case of a shaking screen) or a vibrating motion (in the case of a vibrating screen). Material retained on a given screen passes on to one end of the screen where it is discharged into a hopper or onto a belt. More than one size can be separated by having screens of successively small openings below the initial screen.

E. Test Quarries. - Test quarries aid designers to determine the sizes, shapes, and gradations of rock produced after excavation and handling. Test quarries are usually operated in conjunction with a test fill so that all phases of the rock behavior, from blasting to compaction, can be evaluated. Variables in the quarrying operation include drilling and blasting techniques, and loading, processing, and hauling procedures and equipment. A properly executed test quarry program will (1) provide designers and field personnel valuable information pertinent to excavation design, effect of geologic structure on product, and best blasting techniques and rock fragmentation control to be used: (2) provide representative materials for test fills; (3) give prospective bidders better understanding of the drilling and blasting behavior of the rock; and (4) determine what processing, if any, of the rock will be required.

Even though test quarries are usually established during design, contracts are frequently administered by the construction division, working in cooperation with design engineers. It is desirable, if possible, that construction personnel assigned to the test quarry be later assigned to the dam construction. These personnel will have gained valuable insight on construction procedures and material behavior and form an important nucleus when staffing for dam construction.

Construction control consists of ensuring that the different test methods and procedures called for in the plans and specifications for a test quarry are followed so that comparisons of the different methods and analyses of other information will be meaningful. It is imperative that comprehensive and accurate records be maintained throughout the job. Records should include types of drilling equipment used; rates of drilling in each type of rock; hole diameter, depth, pattern, and spacing; types of explosive, powder factor, and spacing; stemming material and procedures; time sequence of firing; and details of results obtained.

Figure 10.7 - New Waddell Dam, Arizona - Photo of the Processing Plant Used to Produce Filter and Drainage Material, USBR, 1990

1. Grizzly
2. Vibrating Screen
3. Rock Crusher
4. Sand Screw (Wet)
5. Articulating Conveyor Stacker
6. Settling Ponds for Cleaning Processing Water
7. Oversize Material
8. Filter Material
9. Drain Material

10.10F

F. Obtaining Specified Rock Fill. - Specifications prescribe the gradations of rock fill to be placed in the various zones. It may be possible to obtain acceptable material directly from blasting, but conversely, rock may have to be processed in one form or another. The contractor's method of operation has a significant effect on the gradation of rock obtained. Therefore, the designer should be familiar with methods of operation that influence the rock fill.

1. Drilling and Blasting. - It is, of course, most desirable to obtain the correct gradation of rock directly from the piles of blasted rock. However, this is not always easy to do, and generally some experimentation on the contractor's part is necessary. The first experimental shots should provide criteria for establishing a satisfactory drilling and blasting pattern. Spacing of boreholes and the intensity of the charge depend on the in situ rock condition.

Rock is excavated or quarried either by the "bench method" using vertical holes, or by "coyote holing." The coyote method involves firing large charges of explosives placed in tunnels driven into a rock face at floor level. It is initially cheaper than the bench method, but frequently results in an excess of fines and oversize rocks that require secondary blasting. As a general rule, the coyote method should be prohibited when quarrying for rockfill structures.

In quarry experimentation, the material broken by the first blast should be cleared away not only to determine if the correct gradation has been achieved, but to examine the excavation rock face and the condition of the excavation floor. The power shovel has already been mentioned as the best means of loading blasted rock in quantity, but it must be operated from a relatively level floor.

In a normal shot, the coarser material will be to the outside, away from the face and on top; the finer materials will be concentrated toward the working face and at the bottom. The operator of the loading equipment should be cautioned and instructed on correct loading procedures that will help ensure a uniform distribution of sizes in each load if the rock is used in a specific zone without processing. In many quarries a layer of fines will become concentrated on the quarry floor as loading progresses and must either be used elsewhere or wasted.

2. Processing. - If the contractor cannot obtain the correct rock sizes by blasting or if special treatment is called for in the specifications, processing will be required. The amount of processing required will depend on the results of the blasting unless processing procedures are specifically set forth in the specifications. The different types of separation equipment and their purposes were discussed previously.

The degree of processing will vary from using a simple grizzly to remove oversize rocks, or washing to remove excess fines, to running material through a crusher plant. Rock crusher plants are not generally used for processing rockfill due to high operational cost. They are, however, sometimes used to produce select filter and drain materials, bedding materials, and transition materials.

10.10G

G. Final Condition of Borrow Areas, Quarries, and Spoil Areas. - Generally no treatment is required for reservoir-side borrow areas located below minimum operating pool elevation unless there is a stability concern. However, for reservoir-side borrow areas located above this elevation and land-side borrow areas, some treatment is generally required to eliminate what would otherwise be unsightly scars. Treatment of these borrow areas usually begins with the contractor stockpiling topsoil when the borrow pit is first opened. After all usable borrow has been removed (the contractor should not be allowed to excavate to bedrock, but should be required to leave a foot or two of soil over rock), the previously stockpiled topsoil should be spread back over the borrow area and graded to a smooth, uniform surface, and graded to drain. For the case of steep slopes, benches or terraces may have to be specified to help control erosion. As a final step, the entire area should be fertilized and seeded. These procedures are intended to prevent erosion and restore the borrow area to a pleasing aesthetic appearance and possibly make it available for future use.

H. Quarries. - Abandoned quarries are not only unsightly, but may be a hazard. Insofar as practicable, old quarries should be drained and provisions made to prevent any future ponding of water in them. All slopes should be scaled and trimmed back to eliminate the probability of falling rocks or debris. All areas that can support vegetation should be seeded. In some cases, fencing may be needed to restrict free access.

I. Spoil or Waste Areas. - Specific areas must be provided for the disposal of waste or spoil materials. These areas should be clearly shown on specification drawings. Unsuitable material is first used to fill and shape depressions such as ditches, sloughs, etc., located outside the limits of the embankment. Waste materials in excess of that required to fill these depressions may be used upstream to reinforce seepage blankets or as berms to add to the stability of the structure. Waste areas located downstream of the embankment must be carefully selected to avoid interference with any component of the structure or creation of undesirable areas requiring excessive maintenance or remedial work. Waste materials should never be permitted to block seepage from drains, pervious zones, or rock toes, or the disposal area be located such that it could cause contamination of natural ground water. Generally, compaction of material in waste areas is not needed other than that produced by hauling equipment except on the finished outside slopes. Surfaces should be left reasonably smooth and sloped to provide drainage away from the embankment and construction activities. Outside slopes of waste areas composed of easily erodible materials should be compacted or tracked-walked to prevent erosion. If possible, the areas should be fertilized and seeded to improve their appearance and to prevent erosion, thus possibly making them suitable for recreational purposes.

10.11

EMBANKMENT CONSTRUCTION

FILL PROCESSING AND COMPACTING EQUIPMENT

.11

A. Heavy-Compaction Equipment. - The three principal types of heavy equipment used to compact embankment fill are the tamping roller (sheepsfoot), the rubber-tired roller, and the vibratory steel-wheel roller. Other general-purpose equipment sometimes used to compact fill are the fill hauling and spreading equipment itself, which is routed over fill to be semi-compacted and crawler tractors which sometimes can produce adequate compaction of pervious cohesionless materials.

B. Hand-Operated Compaction Equipment. - For compacting in restricted areas, (such as those immediately adjacent to concrete walls, around conduits, or in depressions in rock surfaces) hand-operated, powered tampers weighing at least 100 lb (45 kg) or hand-operated, vibrated plate compactors are used. Vibrated plate compactors are effective only in clean cohesionless backfill. Figure 10.8 shows hand compaction against a steep surface at Ridgway Dam, Colorado.

Fig. 10.8 - Ridgway Dam, Colorado - Hand Compaction Along Formed Dental Concrete on Impervious Foundation, USBR, 1983

10.11C

C. Spreading and Processing Equipment. - Spreading and processing equipment commonly used on embankment fills are as follows:

1. Crawler and Rubber-Tired Tractors and Dozers. - These tractors are used to tow compactors, disk plows, harrows, etc., and when equipped with dozer blades, to move and spread material and to remove oversize stones from embankment fill.

2. Motor Graders (Road Patrols). - Graders are used to spread and mix material; to dress up boundaries between different zones, such as core, transition, and filter zones; to work out oversize particles; and to scarify surfaces of previously compacted lifts.

3. Disks. - Towed by rubber-tired or crawler tractors, disks are used to scarify surfaces of previously compacted lifts and to aerate or blend water into uncompacted lifts prior to compaction. Figure 10.9 shows a disk plow that was used at New Waddell Dam. The depth and angle of the plow should be adjustable from the operator's position on the towing equipment.

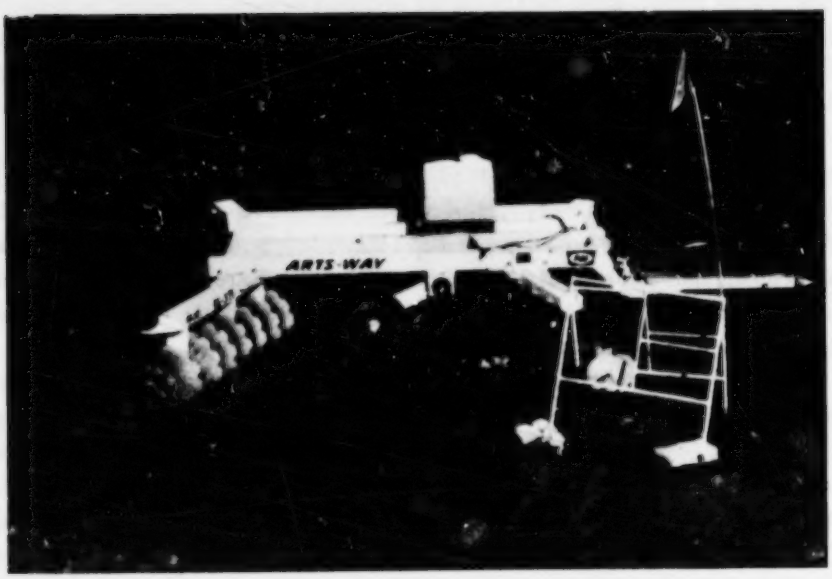

Fig. 10.9 - New Waddell Dam, Arizona - Disk Plow Used for Conditioning and Scarifying Impervious Fill, USBR, 1990

10.12

TEST FILLS

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A. Rock Test Fills. - In the design of rockfill dams, construction of test embankments can often be of considerable value, and in some cases it is absolutely necessary. Design engineers should manage the tes fill program, although construction personnel may administer the contract under which testing is perform Test fills aid the designer by defining the effects of variables of which there would otherwise be little knowledge. A properly executed test fill program should determine (1) the most effective type of compaction equipment, the lift thickness, and the number of passes; (2) maximum rock sizes; (3) the am of degradation or segregation occurring during hauling, placing, and rolling; and (4) physical properties o the in-place fill, such as density and grain-size distribution. Knowledge developed and consequent improvement of design can significantly influence cost of the structure.

Test fills are often constructed in conjunction with test quarries. This practice not only provides informa about rock behavior during quarrying procedures, but also ensures that the material used in the test fill i representative of the material that will be produced by the proposed rock excavation. As in test quarries test fill programs are often administered by both construction and design personnel, and it is advisable, w possible, to assign the construction personnel involved in the test fill program to the actual dam construction.

Construction control of a test fill should be very exacting; otherwise data obtained may be of questionabl value. Plans and specifications for the test fill are prepared by design engineers to evaluate construction procedures and material behavior so that results of the test fill can be used in the design and constructio the prototype; therefore, requirements for constructing the test fill must be clearly conveyed to the construction staff.

Records should be kept up to date, and data plotted daily, as changes in the test program may be necessa to obtain the desired information. The type of records and data required should be established by the design office. It is important to record any and all observations no matter how insignificant they may see at the time. Photographs and records of visual observations are extremely important as they often provid answers to perplexing questions that would otherwise go unanswered. Designers should actively participa in test fill construction so required data is ensured.

Gradation tests should be performed on the rock before and after compaction has been completed. A comparison of before and after gradation curves will indicate the probable amount of particle breakage to be expected during handling and compaction. Lift thicknesses must be measured. In-place density of the compacted material after rolling must be determined directly by large-scale conventional methods or indirectly by observing settlement of the fill. The latter method is generally used because conventional density tests in rock fills are difficult and settlement measurements provide a better relative measurement density. If densification of a layer is determined from settlement readings, caution must be exercised to

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ensure that the settlement measured is in fact that of the layer in question and does not include settlement of the foundation or underlying layers. Settlement in the foundation and within lifts can be determined from settlement plates. In any case, a number of conventional density tests should also be made to supplement the settlement data.

Test trenches should be excavated through the completed test fill for visual observation of compacted lift thicknesses, distribution of fines, and distribution of density. Test fill operations, including inspection of test trenches, should be thoroughly documented with measurements, photographs, and written results of visual observations.

B. Earth Test Fills. - Test fills for earth embankments are often necessary to establish the proper loose lift thickness and the number of passes required to compact soils for which there is no previous compaction experience. Test fills may be needed to determine the best procedure and equipment for adding and mixing in water so as to obtain the desired water content uniformly throughout the lift. Test fills are also constructed (at the contractor's expense) when the contractor wants to use equipment other than that permitted by the specifications, as the contractor must prove that desired results can be obtained with the proposed equipment. Test fills are also used to determine if desired densities can be economically obtained in the field. A test fill is often a part of the embankment, and if satisfactory results are achieved, the compacted fill can be used as part of the embankment fill.

IMPERVIOUS AND SEMIPERVIOUS FILL

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A. Definition. - Impervious materials include clays (CH and CL), clayey sands or gravels (SC or GC), and silty clays (CL-ML); semipervious materials include silts (ML) and silty sands or gravels (SM or GM). Note that sands with borderline gradations classifying as SW-SM, SW-SC, SP-SM, or SP-SC, that is sands having as high as 12 percent passing the No. 200 sieve (5 percent is the usual upper limit for a material to be classified as pervious), may have the characteristics of semipervious material even though such materials may be allowed by the specifications in embankment zones designated "pervious fill." Generally, compaction curves indicating adequately defined optimum water contents and maximum dry densities can be developed using the standard compaction tests on impervious and most semipervious materials.

B. Compaction Specifications. - Requirements of the more important compaction features (such as water content limits, layer thickness, compaction equipment, and number of passes) will be contained in the specifications and will be checked closely by the inspection force to ensure compliance.

Specifications will generally state the type and size of compaction equipment to be used and require that the contractor furnish the Government the manufacturer's data and specifications for the equipment. Those data should be checked against the job specification requirements along with a visual inspection to ensure that the equipment is in condition to produce the required compaction. If a sheepsfoot or tamping roller is to be used, some of the items to be checked include: drum diameter and length; empty weight and ballasted

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weight; arrangement of feet and length and face area of feet; and the yoking arrangement. For a rubber-tired roller, the tire inflation pressure, spacing of tires, and the empty and ballasted wheel loads should be checked. For a vibratory roller, the static weight, imparted dynamic force, operating frequency of vibration, and the drum diameter and length should be checked.

The uncompacted, or loose lift, thickness will be specified. The lift thickness specified will be based on the type of material and the compacting equipment being used. Impervious or semipervious materials are commonly placed in 6- to 9-in (15- to 20-cm) loose lift thicknesses and compacted with six to twelve passes of a sheepsfoot roller or in 9- to 12-in (22- to 30-cm) loose lift thicknesses, with four coverages of a 50-ton rubber-tired roller. When using a rubber-tired roller or any roller that leaves a smooth surface after compaction, scarification of the compacted lift prior to placing the next lift is specified in order to ensure a good bond between the lifts. In confined areas where hand-operated, powered tampers must be used, the fill is commonly placed in 4-in (10-cm) loose lifts and compacted to the densities achieved with sheepsfoot or pneumatic-tired equipment under the previously mentioned conditions. Scarification of hand-compacted surfaces by hand-operated tools, such as a rototiller, is usually necessary because compacted surfaces are almost always smooth.

In-place water content and density must be related to optimum water content and to maximum density in order to judge whether a compacted soil is suitable or unsuitable. Desired minimum densities are normally established during design in terms of a certain percentage ($\geq$ 95%) of maximum dry density,[1] and an allowable range of placement water contents is given in the specifications in relation to the optimum water content of the soil being compacted. (Maximum density and optimum water content are discussed further in the next paragraph). Each soil type will have a different maximum density and optimum water content for a given compactive effort, and it is necessary for in-place field densities and water contents to be compared with laboratory-determined optimum water contents and maximum densities of the same soils. If material being compacted in the field cannot be related to available laboratory compaction data, a compaction test should be performed on that material. It is recommended that check compaction tests be performed by field personnel prior to fill placement to ensure consistency with optimum values obtained during design for the same soil.

Assumptions are made during design regarding shear strength, permeability, and deformation characteristics of the embankment fill. These properties vary according to the density and water content of the compacted soil. This is why the soil must be placed as specified; otherwise design assumptions are not met and distress might occur in the structure. Thus, the desired density and the placement water content range are not arbitrarily established, but are specified for very definite reasons. Both requirements must be satisfied; if the water content is outside its specified range, even though the desired density is obtained, the soil must be reworked and recompacted; if the minimum density is not obtained even though the water content is within

[1] When compaction procedures are set forth in the specifications, the percentage of maximum dry density is not necessarily specified, but if not specified, the desired value is given to field inspection forces by the design office.

the specified limits and specified number of roller passes were performed, additional roller passes at Government expense will be required. Procedures for performing of tests to determine field densities and water contents and the applications of these tests to compaction control are covered in the Earth Manual [4].

C. Compaction Fundamentals. - For a specific soil containing a known percentage of fines, there exists a specific maximum density to which the soil can be compacted by a given amount of energy; but in order to obtain this maximum density, it is necessary for the soil to be at a specific water content. The water content existing at maximum density is termed the optimum water content. The maximum density and optimum water content are determined in the laboratory by compacting five or more specimens of the same soil at different water contents by a test procedure that uses a standard amount of energy; this energy is termed "standard compaction effort." (A detailed description of the laboratory compaction test to establish maximum density and optimum water content is contained in the Earth Manual, USBR Procedures 5500 and 5515 [6].

Two variables that greatly influence fill densities are field compactive effort (that applied by the passage of a given piece of equipment a given number of times on a given thickness of lift) and placement water content. When the water content of a soil being compacted with a specific compactive effort deviates either way from the optimum water content for that effort, densities less than maximum density will result; the greater the deviation, the lower the density. For a soil with a water content on the dry side of optimum or at optimum, an increase in compaction effort will generally increase the density. For a soil with a water content considerably greater than its optimum water content, an increase in compactive effort will tend to shear the soil but not further densify it.

Compactive effort can be increased by increasing the contact pressure of the roller on the soil, by increasing the number of passes, or by decreasing the lift thickness. The combination of variables for use on any given job will depend upon the difficulty of compaction, the degree of compaction required, and economic considerations.

D. Simple Control Procedures. - Simple controls using both visual observations and rough measurements are the primary means by which construction control is performed. They must not be used as the sole means of control, however, but must be supplemented by an extensive program of control testing. For any estimation to be meaningful and accurate, the observer must have both eye and hand calibrated to all conditions expected to be encountered. The designer should consider specifying construction of small test sections prior to the beginning of major fill placement so inspectors, designers, and the contractor can become more familiar with the behavior and compaction characteristics of the fill material and with the performance of the compacting equipment. Noncritical locations are often used for such experimentation, such as in reaches where embankment heights are low.

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Designers should encourage the inspection staff to become thoroughly familiar with the fill material prior the start of fill operations. Time in the field laboratory, performing a few compaction tests to become familiar with the differences in looks and behavior of the various fill materials and to recognize when they are too dry or too wet, as well as when they are at optimum water content is beneficial. Also, Atterberg limits on fine-grained soils and the appearance and feel of the soils when they are at the plastic limit help gauge when the soil is near optimum water content.

A trained inspector should then be able to pick up a handful of soil and make a reasonable estimate of th relation of its water content to its optimum water content by feel and appearance (experienced inspectors often can estimate deviation of water content from optimum within ±1 percent). A soil should be judged for proper water content prior to rolling and check moisture tests made for confirmation. A simple test is to roll out a small amount of the material on a clipboard, or between the hands, and judge how close to th plastic limit it is. This is generally a good indicator, because there is often only a very small difference in the optimum water content and the plastic limit of a soil.

Besides knowing how a soil looks and feels when it exists at the proper density, some method of penetratio resistance is often used as a guide. The method itself could range from the use of a Proctor needle to a common spade. Many inspectors in the past have had good success in estimating density by simply observing the resistance of the compacted soil to penetration by a spade.

Proper lift thickness is fairly easy to estimate once the observers judgment has been calibrated by actual measurements of thickness. A simple measurement for lift thickness is to work a "sharpshooter" spade through the loose lift until the surface of the last compacted layer is encountered. The shovel is marked fo various depths, and the thickness of the layer can be read directly off the spade. This is done just prior to the first pass of the roller and is generally quick and accurate enough for control purposes. However, because many contractors are naturally interested in placing lifts as thick as they can get by with, argument frequently arise on this point. It is for this reason that control of lift thickness by visual observation alone should not be used, but must be supplemented by measurements. The proper and most reliable method fo determining lift thickness is by obtaining elevation across the embankment at predetermined stations every to 5 days, recording the number of lifts, and computing the average lift thickness. It is normal practice for the inspection force to keep records of number of lifts and level surveys for control during construction, and for part of the permanent record and documentation history.

Much information can be gained by observing the action of compacting and heavy hauling equipment on the construction surface. If the water content of the fill material is uniform and the lift thickness is not too great, the action of the roller will indicate whether the water content of the material is satisfactory and if good compaction is being obtained. For instance, if on the first pass of a rubber-tired roller, the tires sink to a depth equal to or greater than one-half the tire width; if after several passes the soil is rutting excessively; or if at any time during rolling, weaving or undulating (as opposed to normal "springing" of the surface) of the material is taking place ahead of the roller, either the tire pressure is too high or, more

likely, the water content of the material is too high. On the other hand, if the roller tracks only vary slightly or not at all and leaves the surface hard and stiff after several passes, the soil is probably too dry. For most soils having proper water contents, the roller will track nicely on the first pass and the wheels will embed 3 to 4 inches (3 to 10 cm); there should always be some penetration into soil at its proper water content, though the penetration will decrease as the number of passes increases. After several passes of a sheepsfoot roller, the roller should start walking out if adequate and efficient compaction is being obtained (walking out means the roller begins bearing on the soil through its feet only -- the drum is riding a few inches above the soil surface). If the roller walks out after only a few passes, the soil is probably too dry; if it does not walk out, but continues churning up the material after the desired number of passes, the soil is too wet or the roller foot contact pressure is too high. Note that soil type also plays a role in the action of the roller and has an influence on embedment depth of rubber tires or the walking out of a sheepsfoot roller. The inspector must be mindful of this influence and become familiar with the soil in calibrating his perspective of its compaction. Another observation to be made is whether or not the feet are coming out clean; the soil is generally too wet when large amounts of material are being picked up by the feet and knocked off by the cleaning teeth. There should be only a minor amount of sticking if the soil is at its proper water content.

At a proper water content there will always be a noticeable "springing" of the embankment surface as it reacts to the passage of any heavy construction equipment; the amount will depend largely on soil type. However, a sudden sinking or rising of the surface under the weight of the passing equipment is a good indication that a soft layer or pocket exists below the surface; if there is no spring at all, it is probable that several lifts of fill have been placed too dry. If such a condition is noticed, it should be checked by the laboratory and the condition corrected if the material is not within specifications.

E. Field Control Testing and Sampling

1. General. - Field control testing (field density tests) and record sampling of compacted fill are conducted for two basic reasons: (1) to ensure compliance with design requirements and (2) to furnish a permanent record of as-built conditions of the embankment. Field control testing consists largely of determinations of the water content, density, and classification of the field compacted material. Record sampling consists of obtaining undisturbed samples (often with companion disturbed bag samples) at selected locations in the embankment during construction. Record samples are usually submitted to the Reclamation's laboratory in Denver for strength and consolidation testing. Index testing and construction control testing are also generally conducted for comparison with field results. The designer must monitor this information to ensure that fill construction is compatible with design assumptions. The designer is responsible for conveying a minimum field control testing and sampling program to the construction staff via construction considerations or letter. It is also helpful if the designers wishes are conveyed verbally through meetings with the construction staff so that questions can be answered and reasons for various requirements can be discussed.

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2. Field Density Testing and Record Sample Programs. - Control testing should be frequent at the start of fill placement; after rolling requirements have been firmly established and inspection personnel have become familiar with material behavior and acceptable compaction procedures, the amount of testing can be reduced. Many factors influence the frequency and location of control tests and record samples. The frequency depends on the type of material and how critical the fill being compacted is in relation to the overall job (an impervious core will naturally require more control than will a random berm, for instance). Sampling should be done at locations representative of the area being checked.

As previously indicated, a systematic testing and sampling plan should be established at the beginning of the job. Control tests laid out in a predetermined manner are usually designated as routine control tests and are performed at the designated locations, no matter how smoothly the compaction operations are being accomplished. A routine control test should be performed for every 1,000 to 3,000 yd^3 (750 to 2300 m^3) of compacted material and even more frequently in narrow embankment sections where only a small volume of material raises the section height considerably. In the first lift above the foundation, tests should be made more frequently to ensure that proper compaction and foundation bond are attained in this important area. A rough guide for taking record samples is one for every 30,000 yd^3 of core fill and one for every 30,000 to 50,000 yd^3 (23,000 to 38,000 m^3) of compacted material outside the core. If record samples are taken primarily for determination of shear strength of the fill, it may be more important in many dams to concentrate more testing in the material outside the core because this is where a major portion of the resistance to sliding is developed. Conversely, if the purpose of record samples is for confirming consolidation parameters, it may be more important to obtain them from the clay core of the dam.

Tests in addition to routine control tests should be made in the following areas: (a) where there is reason to doubt the adequacy of compaction, (b) where the contractor is concentrating fill operations over relatively small areas, (c) where special compaction procedures are being used (power tampers in confined areas, etc.), (d) where instruments are located, and (e) adjacent to abutments and structures.

3. Record Samples. - Undisturbed record samples may be obtained by carefully carving out a block of approximately 1 ft^3 (28 L) from the compacted fill. The sample is then sealed in wax and encased in a wooden box or protected by other methods of packaging against disturbance or loss of water. Undisturbed record samples are also taken by trimming around a large steel cylinder as it is pushed into the fill. Details for obtaining and preserving record samples are described in the Earth Manual [4]. Undisturbed record samples are subjected to shear and perhaps consolidation testing by the Denver Office laboratory, and material from trimmings and unused portions of the record samples or of the companion bag samples are used for laboratory compaction, gradation, specific gravity, Atterberg limits, and other tests. Undisturbed record samples and bag samples must be tested promptly if the results are to be useful in construction control.

4. Field Density Tests. - Field density determination consists of volume and weight measurements to determine the wet density of in-place fill and water content measurements to determine fill water contents and dry densities. Volume and weight measurements can be determined by direct or indirect methods. In direct methods, the weight of the material removed from a hole in the fill and the volume of the hole are used to determine the wet density; direct water content determination involves drying the soil by heating and then weighing the dried soil to determine the amount of water lost. Indirect methods of determining the density and water content involve measurement of a characteristic of the material that has been previously correlated to the density and/or water content. Generally, field density tests should be taken one lift thickness deep.

a. Direct Methods - Direct methods of measuring volume include sand displacement, water balloon, push cylinder, piston sampler, and water displacement methods. Apparatus, procedures, and guidance in obtaining satisfactory results for the sand displacement, water balloon, push cylinder, and piston sampler are given in the Earth Manual [4, 6]. The sand displacement and water balloon methods are the most widely used methods of measuring in-place density because of their applicability to a wide range of material types and good past performance records. The sand displacement method is the most reliable and most frequently used; it should be the referee test for all other control methods. The push cylinder and piston sampler are good for obtaining samples from which the density can be ascertained, but are limited to moist fine-grained cohesive soils containing little or no gravel and moist fine sands that exhibit apparent cohesion. The water displacement method is generally used for testing gravelly soils where holes as large a 1 yd^3 are needed to obtain accurate results. A thin plastic sheet is necessary to line the hole to prevent leakage, and special equipment is often required for handling and weighing the large volume of excavated material and measuring the large volume of water. A 3- to 5-ft (1- to 1.5-m) diameter steel ring with a height about equal to a compacted lift thickness is often used where the fill surface is rough and uneven. The volume of water required to fill the ring with plastic liner in place is determined, the water and liner removed, and then the hole is dug without moving the ring. The liner is then placed in the hole, and the volume of water required to fill the hole to the top of the ring is determined. The difference between the two volume measurements is the in-place volume of excavated fill material. Apparatus and procedures for large volume water displacement tests are described in the Earth Manual, Vol. 2, USBR Procedure 7221 [6].

Water content measurements are required to control placement water contents and to determine dry densities for field density tests. Methods for direct water content determinations include oven drying, hot plate or open flame drying, and drying by forced hot air. Procedures for oven drying are described in the Earth Manual [6]. In the hot plate method, a small tin pan and a hot plate, oil burner, or gas burner (something to furnish fast heat) are used. A specimen of wet soil is weighed, dried by one of the previously mentioned methods, and weighed again to determine how much water was in the specimen. This method is fast, but care must be taken to ensure that the material is thoroughly dry. Also both organic matter and crystalline water may be removed, sometimes

resulting in higher content determinations than those obtained by oven drying. In the forced hot air or "Moisture Teller" procedure, a specimen is placed in a commercially available apparatus containing an electric heater and blower. Hot air at 150 to 300 °F (65 - 150 °C) is blown over and around the specimen for a preset time. A 110- or 230-V source is required. Available sizes of apparatus can accommodate specimen weights from 25 to 500 g. Drying times are estimated to vary from 5 minutes for a sand to as long as 30 minutes for a fat clay.

b. Indirect Methods - Indirect methods of measuring in-place density and water content can possibly be used to effect a closer control of a job than can be accomplished by direct methods alone. However, no indirect method should ever be used without first calibrating it with results obtained from direct methods, and periodic checks by direct methods should be made during construction. If reliable calibrations can be obtained then the results from indirect methods can supplement the results from direct methods; indirect methods should never be used in lieu of direct methods. Indirect methods include use of the nuclear moisture-density meter and the Proctor penetrometer (often referred to as the "Proctor needle").

(1) Proctor Penetrometer - The Proctor penetrometer is generally accurate only under ideal conditions; it requires careful calibration using soils of known density and water content and considerable operating experience, and even then the results may be questionable due to the great influence of a non-uniformity of water content or that which a small piece of gravel can have on penetration resistance. It is, therefore, not recommended for general use in compaction control; it can be, however, a very useful tool in supplementing visual observations and providing a general guide for detecting areas of doubtful compaction. The procedure (needle-moisture test) for determining the relation between wet unit weight, penetration resistance, and water content is described in the Earth Manual.

(2) Nuclear Method - The nuclear method is an expedient means by which both water content and density determinations can be made more rapidly than by conventional direct methods. Recent advances in the design of nuclear equipment and a better understanding of nuclear principles involved have led to increasingly widespread use of nuclear gages. The nuclear method is not permitted as a primary control, but is used to supplement direct methods. Use of nuclear density devices should be in accordance with the manufacturer's recommendations. Appropriate safety precautions should always be observed.

5. Test Pits. - It is sometimes desirable to excavate deep test pits to determine the overall condition of the compacted embankment. Field density tests can be made and undisturbed record samples can be obtained at various elevations as the pit is being dug. The degree of uniformity of water content with depth can be obtained by testing specimens from frequently spaced depths. An important advantage of the test pit is that it allows visual inspection of the compacted fill; soft spots can be detected and it can be determined whether bonding of fill lifts has been accomplished. Near the

foundation, test pits are used to check bond of the impervious zone to the foundation. Large-diameter bucket auger holes (30 to 36 in) can also be used effectively for these purposes. All tests and visual observations should be thoroughly documented, including numerous photographs. Test pits must be backfilled with appropriate, properly compacted soil.

6. Methods of Relating Fill Density and Water Content to Maximum Density and Optimum Water Content. - The fill density and water content must be related to laboratory values of maximum density and optimum water content of the same material in terms of percent compaction and variation of fill water content from optimum. For this comparison to be meaningful, valid laboratory values must be selected.

Performance of the standard five-point compaction test on field density test material is the ideal as it produces values of maximum dry density and optimum water content for that particular soil. However, performance of this test is time-consuming and it is generally not possible to perform the five-point test on material from each field density test.

There are other less time-consuming methods for comparing the field density material with one of the soils on which standard laboratory compaction tests have been performed in connection with design studies and during construction. The means of identification for comparison are:

- USBR rapid compaction control (preferred method)
- Atterberg limits correlations
- Grain-size distribution correlation (sometimes used for coarse-grained soils)
- Visual comparison

Each of these tests is discussed in detail in the Earth Manual [4, 6]. Atterberg limits correlations are based on correlations of liquid limit, plastic limit, or plasticity index with optimum water content and maximum dry density. In the USBR rapid method, a wet density compaction curve is developed for the fill material from three wet density compaction points, and the percent of maximum dry density and deviation from optimum water content are computed without the immediate need for water content values. The visual method consists of establishing by visual examination that the field density material is the same as one of the materials for which laboratory compaction curves were developed. It is a frequently used method, but is the least desirable because materials that look very much alike and have the same soil classification can have widely varying compaction curves. The USBR rapid compaction control method is the most accurate, and is the preferred method.

7. Procedures for Gravelly Soils. - Results of the five-point and visual methods are usually correlated directly with field density test results if all the material is minus No. 4 sieve size. However, Atterberg limits correlations and USBR rapid methods are based on the minus No. 4 sieve size fraction; consequently, field density test results must be corrected to obtain the water content and density of the minus No. 4 fraction. Corrections must also be applied to field results if the laboratory compaction curve is based on a scalped material (corrections would not be made if particles larger than 2 in (5 cm) are replaced with an equal weight of particles from 2 inches to the No. 4 sieve and tested in the laboratory in an appropriate large compaction mold). The equations necessary to make these corrections and procedures for applying them are given in the Earth Manual [6], USBR Procedures 7205, 7220, 7221, and 7230.

8. Evaluation of Test Results and Subsequent Actions to be Taken. - As soon as field test results have been obtained, they are related to appropriate values of maximum dry density and optimum water content to ascertain whether specification requirements have been met. If test results equal or exceed specification requirements, the next lift can be added; if test results definitely do not meet specification requirements, corrective measures must be taken immediately. A lift must be rejected if the material is too wet or too dry. If the density is too low, but the water content acceptable, additional rolling is generally all that is required. If, however, the water content is outside specifications, the entire lift must be reworked and rerolled. A lift too wet should be worked by disking until the water content is lowered to an acceptable value and then recompacted. A lift too dry should be disked, sprinkled, and disked until the additional water is uniformly distributed, and then recompacted. It is important when reworking a rejected lift that the full depth of the lift is reworked, not just the upper portion. All reworked lifts should be retested for density and water content. It is desirable to determine the reason for the unsatisfactory condition of a rejected lift, whether in borrow operations or operations on the fill, so that conditions may be corrected on future lifts.

F. Operations in Adverse Weather

1. Cold Weather. - Good compaction is not obtained if the soil is frozen; even at temperatures above freezing. Research [5] has shown that cold weather may make it more difficult to obtain good compaction, and the Project Construction Engineer may be faced with a difficult problem in deciding just exactly when it becomes too cold for further fill placement. There are no definite criteria for establishing the temperature below which satisfactory work is impossible. The rate at which unfrozen soil loses heat and freezes is dependent on the size of the construction surface and the rate of fill placement. The important thing is to keep the construction surface "active," i.e., to continue fill placement without extensive interruptions. At some dams, work has been continued in 20 to 30 °F (-7 to -1 °C) weather, 24 hours per day, 7 days per week, in order to keep the construction surface active. Work must be terminated whenever water in the soil freezes quickly and equipment operation becomes difficult.

Protecting the construction surface during the winter when operations are shut down is another problem. The degree of protection of course depends on the severity of the winter. In many parts of the United States, it is not necessary to use any protection if the embankment surface was properly seal rolled. The worst damage is a heaving and loosening of the upper several inches of the embankment fill by frost action. Before construction starts again in the spring, the surface material should be excavated to a depth below the line of frost action. The depth to excavate is best determined by the use of frost tubes supplemented by visual examination of shallow test holes. In colder climates where the embankment freezes to a depth of several feet, it may be desirable to protect the construction surface during the winter with several feet of loose material. Other methods of protection have been used in extremely cold areas, such as ponding water over the construction surface or even using some type of heating coils on foundations for structures (spillway, outlet works tower, etc.).

2. Wet Weather. - Fill placement during periods of high precipitation always presents a problem due to the necessity of maintaining proper water content. Impervious materials should never be placed on the embankment during rains, though construction operations can often be continued successfully between rains. The water content of material spread on the embankment can be reduced somewhat during periods of no rain by plowing or disking, before rolling.

It is desirable to compact fill material as soon as possible after spreading to minimize the time loose fill is exposed to precipitation. Rubber-tired rollers are superior to sheepsfoot rollers when rains are frequent because they leave a relatively smooth compacted surface, whereas the sheepsfoot roller leaves a loose rough surface that readily soaks up rainwater. If a sheepsfoot roller is used for general compaction, smooth-wheel rollers (steel or rubber) can be employed to seal the surface when rain is imminent. Pneumatic-tired equipment is faster than a smooth drum roller and, therefore, often preferred for sealing the fill surface when rain or snow is imminent. In any event, the construction surface should be kept sloped to allow water to run off instead of standing in puddles and soaking in. After a rain, if some ponding does occur, it is usually expedient for the contractor to put in a few small ditches to drain these areas.

It is often necessary after a rain to scarify and work the construction surface to a depth below that of excessive moisture penetration until it is dried to a satisfactory water content or to remove and waste all affected material. If the described procedures for facilitating runoff are followed, the depth of moisture penetration will be kept to a minimum.

3. Dry Weather. - If the material being dumped on the fill is too dry for proper compaction, water must be added to it by sprinkling the soil after it is spread and before it is rolled. The amount of water to be added and the amount of blending required to ensure uniform moisture distribution throughout the spread layer depend on the fineness and plasticity of the soil. The soil must then be worked with disks to thoroughly blend the added water into the soil. The importance of uniform moisture distribution cannot be overemphasized, for if water is retained in pockets of wet soil, very poor compaction will result.

Sprinkling the soil can be accomplished by hosing from a pipeline, located either along the embankment toe or crest, or by the use of water trucks. The latter method is the most effective and is most commonly used today. Pressure sprinkling systems on trucks are superior to gravity systems and should be employed if at all possible. Water sprays must not be directed on the soil with such force as to cause fines to be washed out. Until inspectors and contractor personnel have gained a "feel" for the amount of water needed, rough computations of the number of gallons to add for a given area should be made, and water applied accordingly. After a few trials, a feel for the proper amount will develop. The coarser and less plastic the soil, the more easily water can be added and worked uniformly into it. It is very difficult to obtain uniform moisture distribution in plastic clays containing lumps, without a "curing" period of a few days; this is, of course, not practical on the embankment surface. Consequently, disking followed by addition of water and then thorough mixing with a heavy rotary pulverizer may be required to obtain uniform distribution of water in such soils.

G. Compaction in Confined Areas. - Confined areas are those where normal rolling operations with heavy equipment are restricted or where heavy equipment cannot be used at all and hand compactors must be employed. Compaction with hand compactors should be avoided and heavy equipment used in these areas if at all possible. Confined areas, where heavy equipment can often be used on a careful basis if maneuvering room is available, include fairly smooth abutments (rock or earth), conduit barrels, towers, etc. Confined areas where hand compactors often must be employed are adjacent to thin concrete structures such as wing walls, guide walls, etc., where heavy equipment might damage the structure; adjacent to rough, irregular rock abutment slopes where heavy equipment cannot get close enough to the surface to squeeze the fill into all the irregularities and openings in the rock; and around alignment collars or plugs where maneuverability is a problem.

1. Heavy Equipment. - When conditions are such that heavy compaction equipment can be used to compact soil against rock abutments or walls of concrete structures, the construction surface of the embankment should be sloped away from the rock or concrete at about 1:6 (V:H) for a distance of 8 to 12 feet (2.4 to 3.6 m). This will allow the roller to act more directly in compacting the soil against the abutment or structure. The area can then be rolled perpendicular to the face of the abutment or structure by heavy pneumatic equipment or a sheepsfoot roller or by heavy pneumatic equipment in a direction parallel to the face.

2. Hand Compactors. - If heavy rollers cannot be used as describe previously in paragraph (a), the roller should be allowed to work as close as possible, and the portion of the embankment directly against the rock or concrete should then be compacted with smaller equipment in thinner lifts. Smaller equipment refers to hand-operated power tampers, as shown in figure 10.8, or power tampers mounted on small tractors. These tampers are usually gasoline-operated or operate on compressed air. The hand-operated power tampers (sometimes called rammer compactors) are probably the most widely used equipment for compacting fine-grained soils in confined areas. A loose lift thickn s of not more

10.14

than 4 inches (10 cm) should be employed in conjunction with the use of these power tampers. The compactors should have a minimum static weight of 100 lb, and the inspector should carefully check to ensure that the manufacturer's recommended air pressure is being developed. Experience has shown that 2- x 4-inch wood rammers, or single-foot compressed air tampers (commonly referred to as "powder puffs" or "pogo sticks") do not produce adequate compaction. It is important that the zones of hand compaction and compaction by heavy equipment overlap so that no uncompacted material exists between them.

It is stressed that hand compaction of embankment materials on dam abutments is not recommended. Abutments can usually be shaped by proper excavation techniques or the use of dental concrete to eliminate the need for hand compaction requirements. Wheel rolling is the generally accepted method if the specified roller can not be used. Equipment-operated mechanical tampers should be used instead of hand-operated compactors and only for special situations.

Where impervious material is to be placed adjacent to abutments or concrete structures, it should be as fine-grained as practicable. The soil must be plastic enough to penetrate all irregularities in the abutments and to form a well-bonded seal with the foundation. The moisture content is often increased slightly (1 percent or less) to produce more plasticity in these areas.

Closer compaction control must be exercised in these areas than in the main embankment because they are generally more critical with respect to seepage and damaging settlements which can cracking and piping. A special sampling program should be established, and an inspector must watch the operation at all times where power tampers are used.

PERVIOUS FILL

.14

A. Definition. - Pervious fill material is defined herein as free-draining cohesionless sand and/or gravel, containing less than approximately 5 percent of material passing the No. 200 sieve.[2] Standard impact compaction tests on such materials do not yield well-defined values of optimum water content and maximum dry density, and field densities are related to maximum and minimum density determinations made according to relative density procedures given in USBR Procedures 5525 and 5530 of the Earth Manual [6] rather than to maximum dry density as determined in the standard compaction test.

[2] Outer embankment zones of some dams composed of coarse-grained soils which contain appreciable amounts of fines (i.e., > 5 %) are sometimes designated as "Pervious Zones." Compaction equipment, procedures, and control for such materials can be either those presented in this section or those presented in section 10.13 for impervious and semipervious fill. The decision as to which method to use depends on whether the soil behaves like a pervious material or more like an impervious material. Experience and/or laboratory tests will usually determine, but test fills may be necessary to establish most efficient procedures.

B. Compaction Equipment. - Vibratory steel-wheel rollers in the weight range of 5 to 10 tons are the bes equipment for compacting pervious sands and/or gravels. Drum-drive self-propelled vibratory rollers have been found to be effective on fine uniform sands when other vibratory rollers were not. Figure 10.10 show a vibratory roller compacting filter material at New Waddell Dam. Rubber-tired rollers are sometimes specified, and crawler tractors are sometimes used if they can produce required densities. Crawler tractors are sometimes effectively used in rough or hilly areas where a vibratory roller cannot operate well, for example, in compacting a horizontal drainage layer on an undulating foundation. The contact pressure of the tractor should be at least 9 lb/in^2 (56 kPa), and the tractor should operate at that speed which imparts the greatest vibration to the fill.

Where free-draining pervious material is placed as backfill against concrete walls and around concrete structures such as outlet conduits, small compaction equipment is needed because of restricted area or because heavy equipment is not allowed close to the walls. Two common types of small vibratory compactors are a small steel-wheel vibratory roller or a "vibrating plate" compactor. Air-operated concrete vibrators have also been used successfully in densifying narrow, relatively deep zones of pervious backfill. Figure 10.11 shows pervious fill being placed on the spillway foundation at Fruitgrowers Dam, Colorado. The pervious material beneath the bottom and adjacent to the walls of the spillway were compacted by a hand-operated vibratory roller. Vibratory-type units should be checked frequently to ensure that they are operating at a frequency level giving the highest possible density. For cohesionless materials, the frequency of vibration should generally fall between 1,100 and 1,500 vibrations per minute.

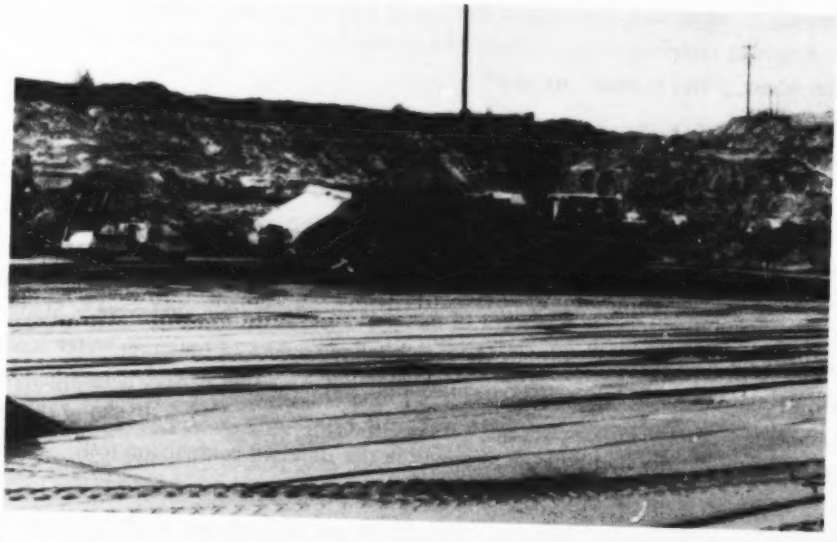

Figure 10.10 - New Waddell Dam, Arizona - Bottom Dump and 10-Ton Vibratory Roller Placing and Compacting Filter Material in the Downstream Blanket Drain, USBR, 1990

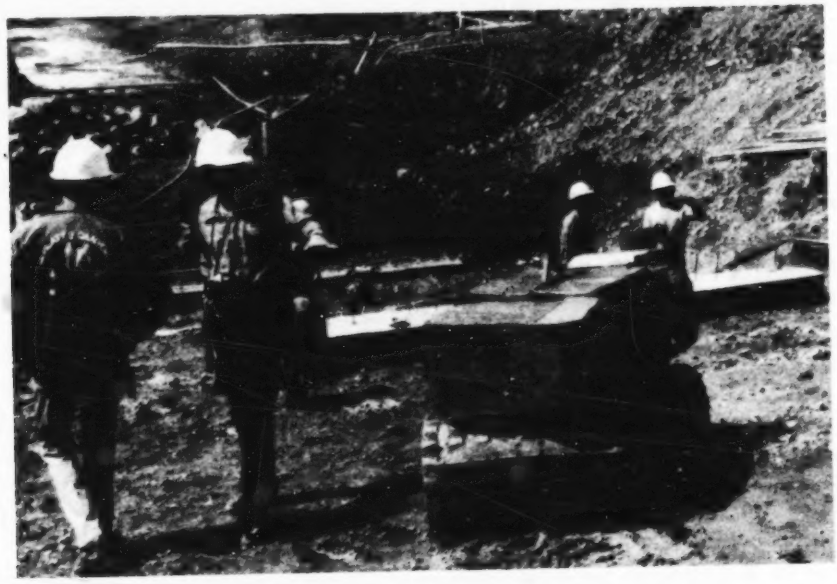

Fig. 10.11 Fruit Growers Dam, Colorado - Hand-Operated Vibratory Roller Used for Compacting Pervious Fill Beneath and Adjacent to the Spillway, USBR, 1986

C. Material Graduations. - Gradations of materials to be placed in the large pervious embankment zones are generally not specified except to restrict the maximum size and/or the percentage by weight of particles smaller than the No. 200 sieve. On the other hand, a particle-size distribution within limits defined by roughly parallel gradation curves on the standard grain-size plot is specified for select pervious materials to be used in horizontal and inclined filter drainage layers.

D. Water Content Control. - If the pervious material is gravel, no water content control is necessary and the material is simply compacted in its as-received condition. If the material is sand or contains significant proportions of sand sizes, the material is maintained in as saturated a condition as possible during rolling by using water trucks with pressure spray bars, hoses connected to header pipes laid along the embankment, or other approved methods. The effect of insufficient water in a pervious sand is to cause the sand to "bulk" (i.e., exhibit apparent cohesion) which will result in low strength and density when it dries out. It is, therefore, imperative that the sand be saturated as the roller passes over it, which is admittedly sometimes difficult to do because of the perviousness of the sand. Figure 10.10 shows a sand filter at New Waddell

10.14E

Dam that was wetted by a water truck with a pressure spray bar system. Note the standing water in the foreground. If a so-called pervious material contains appreciable proportions of fines, say more than 5 to 10 percent passing the No. 200 sieve, it may be necessary to use water content control to ensure that the water content is within a range that will permit desired compacted densities to be obtained.

E. Lift Thicknesses and Numbers of Passes or Coverages. - These will be established in the specifications. Pervious fill is commonly placed in 6- to 15-in (15- to 38-cm) loose lifts when it is to be compacted by three or four passes of a vibratory steel-wheel roller or a 50-ton rubber-tired roller, or in 6- to 8-in loose lifts when it is to be compacted by three to six coverages of a crawler tractor.[3] In confined areas where small vibratory rollers or hand-operated vibrating compactors are required, material is normally placed in 2- to 3-in (5- to 7.5-cm) thick layers with vibratory compaction applied until densities comparable to those required for areas compacted with heavy equipment are achieved.

F. Density Requirements. - Compaction equipment and procedures and desired density are normally specified. The expectation is that the prescribed field compaction methods will produce the desired densities. If these densities are not achieved in the field, then the contractor is paid for additional rolling. Generally, the average in-place relative density of pervious fill shell zones should be at least 85 percent. Fill in filter drainage zones should have a relative density no less than 75 percent.

G. Construction Control

1. Simple Control Procedures. - Checking lift thicknesses of pervious fill can possibly be accomplished using the same procedures described for impervious and semipervious materials (sec. D.), except that when using a shovel or rod it is often difficult to determine when the top of the underlying compacted layer is reached. This procedure is also not practical in fills containing large gravel particles. In some cases, it is possible to excavate a small hole in the loose material to the top of the underlying layer, which is identified by a relatively higher resistance to digging.

The embankment should always be graded so that surface waters will not wash fines from impervious or semipervious fill materials into the pervious fill (filters and drains). During construction of earth dams, placement of filter materials for drainage layers should always be kept higher than adjacent fill containing fines to prevent spillage of fine-grained soil onto the pervious material or to reduce the possibility of washing of fine-grained soils into the material by surface runoff. Designers and construction staff should learn to recognize the appearance of pervious material which meets

[3] Guide Specifications generally call for a specific number of "complete passes" of a rubber-tired roller or vibratory steel-wheel roller; defining a "complete pass" as the coverage of the entire lift to be compacted with the roller specified. It is apparent that this concept does not apply to compaction with a crawler tractor as a unit because of the wide separation of its tracks. Therefore, when compaction by a crawler tractor is specified, the specifications should require so many coverages by the tracks of the tractor.

specifications so they can more easily detect, without the delay of testing, the presence of excess fines. A good indicator of excessive fines is when the hauling and compacting equipment sinks in and causes ruts in the fill surface. This usually indicates that water applied during compaction is not draining through the material as it should because of reduced permeability from excess fines.

In general, a vibratory roller should push only a small amount of material ahead of it and leave a smooth surface behind on the first pass. If the roller sinks in and pushes a large amount of material in front of it, either the frequency of vibration is not correct for the particular soil being compacted or the material contains too many fines.

It is more difficult to judge the compacted density of pervious material than that of fine-grained material. Resistance to penetration of a shovel or a reinforcing steel rod is not a suitable way of checking density, and it is necessary for the inspector to rely more heavily on field control tests. Some inspectors can judge the compaction obtained in pervious fill by walking over it and feeling the reaction of the material. The uniformity of particle-size gradations in the lift should be observed. Too much vibration may cause segregation of the fill material, causing the fines to settle to the bottom of the lift. On the other hand, if particles are being crushed during compaction, a layer of fines will develop in the upper few inches of the lift.

Loading, dumping, and spreading operations should be observed, particularly if the pervious fill is well-graded material, to ensure that undesirable segregation of particles is not occurring as a result of such operations.

The particular importance of horizontal and inclined drainage layers to the function of a dam, and the fact that these features are so limited in thickness, justify special attention to see that gradations and densities of the in-place filter materials meet specifications.

2. Gradation. - Gradation tests should be performed to ensure that the material being placed is within specification limits. The number of gradation tests needed will, of course, depend on the variability of natural pervious material as obtained from the borrow areas. Complete gradation tests should be performed on material for which the entire range of particle sizes is specified. For those materials for which only the percent finer than the No. 200 sieve or some other sieve is specified, the material should be soaked and then washed over the No. 4 and the designated sieve in accordance with procedures given in the Earth Manual, USBR Procedure 5335 [6]. Gradation tests should also be performed on compacted material especially when it is suspected that there has been contamination with fines from surface waters or when the fill material may have been degraded by breakage of particles during compaction.

3. Field Density Testing and Relative Density Determinations. - The sand volume density test method described in the Earth Manual, USBR Procedures 7205 and 7220 [6] can be used to determine the in-place density of pervious fill classifying as sands and finer gravels. It is, of course, more difficult to dig the holes in pervious materials. When the fill material contains large proportions of large particles, it may be necessary to increase the volume of the holes substantially and to line the holes with plastic film so that the volume can be determined by the quantity of water or oil needed to fill it. The nuclear density meter can be used for supplementary density determinations under the conditions stated in paragraph .13.E. The density of free-draining pervious fills and filter material cannot be related to standard impact compaction test results because water content-density relations are not valid for such materials as they are for materials having varying degrees of plasticity. Field densities must be expressed in terms of maximum-minimum densities as determined by laboratory tests described in the Earth Manual, USBR Procedures 5525, 5530, and 7250 [6]. Field densities are expressed in terms of their relation to these laboratory values, i.e., in terms of relative density. The relative density D_d of in-place material can be computed by this equation:

$$D_d\% = \frac{\gamma_{dmax}(\gamma_d - \gamma_{dmin})}{\gamma_d(\gamma_{dmax} - \gamma_{dmin})} \times 100$$

γ_d = dry unit weight of the pervious fill in place (in-place density), lb/ft^3 (kg/m^3)
γ_{dmin} = minimum density, lb/ft^3 (kg/m^3), from laboratory tests
γ_{dmax} = maximum density, lb/ft^3 (kg/m^3), from laboratory tests

Field density determinations using the sand volume procedures should be made for every 1,000 yd^3 (765 m^3) of pervious fill placed at the beginning of the job and for every 3,000 yd^3 thereafter, with more frequent test determinations desirable for drainage layers. These tests should generally be taken one-lift-thickness deep, especially in sands. Although the performance of maximum and minimum density determinations on material from each field density test would give the most accurate determination of the relative density of the inplace material, this is frequently not feasible because of time and manpower restrictions. Therefore, it is often advisable to attempt to develop correlations between gradation data and the maximum-minimum density values on materials representing the range of gradations to be expected from the sources of supply. For example, a correlation between the percentage finer than the No. 16 sieve and the maximum-minimum density values can be developed. Where a good correlation like this is developed, a simple determination of the percent finer than the No. 16 sieve is all that is needed to obtain the appropriate maximum-minimum density values for the in-place material. In other instances, good correlations may be developed between maximum-minimum density values and the coefficient of uniformity or the percent of material passing other sieve sizes. Correlations developed between minimum and maximum density values can be used to obtain minimum density after performance of a maximum density test alone. Caution should be exercised in using such correlations for uniform sands because the spread between the maximum and minimum density is very small and large errors may result in percent relative density.

It is cautioned that correlations such as those described previously should be used only on materials from the particular sources for which the correlations were developed. Application to materials from other geologically different sources may lead to considerable error because of differences in particle shapes and degradation characteristics. Selection of maximum-minimum density values by visual comparisons of minimum density determinations have previously been made, but this is generally not a good procedure; small differences in particle sizes that cannot be adequately detected by visual comparisons have significant effects on these density values.

H. Test Results and Actions to be Taken. - Assume that it has been established that a lift has inplace relative densities between 80 and 85 percent and the minimum average specified is 85 percent. What should be done? A review must be made of all results of previous lifts to ensure that a minimum average of 85 percent relative density will be maintained if the questionable lift is accepted. The intent of the relative density criteria is that the relative densities of the material measured immediately after compaction must conform to the requirements stated in the specifications without any consideration of increase of density caused by the placement and compaction of subsequent lifts.

ROCK FILL

.15

A. General. - Embankments with large rockfill zones are becoming more common. This is primarily due to (a) the necessity for using sites where rock foundation conditions are unsuitable for concrete dams, (b) the suitability of modern construction equipment to handle rock, (c) the increasingly higher dams being constructed, and (d) the economic benefit that is obtained by maximum use of rock from required excavation.

Rock which does not readily break during handling, transportation, and compaction results in a pervious to very pervious fill depending on the amount of fines present. Such sound rock is desirable for rockfill dams, especially if the source is from required excavations, such as for a spillway.

Less desirable rocks break down in varying degrees upon excavation, handling, compaction, and even in situ. These unsound rocks may break down because of their lack of induration; their primary structure, such as thin bedding; their degree of fracturing; their weathering; and other physical and chemical properties. Some examples of generally unsound rocks, as related to large rockfill zones in dams, are shales, mudstones, siltstones, claystones, chalk, earthy limestones, and other sedimentary rocks which may be poorly cemented. Ordinarily sound rocks which are very weathered and very fractured may not be acceptable for rockfill zones because of their susceptibility to breakdown due to the weathering and fracturing.

Because of the unpredictability, in general, of the breakdown of most types of rocks, the use of test quarries and test fills for designing and constructing rockfill dams is widespread.

B. Sound Rock in Rockfill Dams

1. Specifications. - The specifications for pervious rockfill sections generally require that the rock be sound, well graded, and free draining. Gradation is not usually specified, but the maximum permissible size is normally specified together with lift thickness. Rock fill is usually required to be placed by dumping from trucks, with bulldozers spreading the material to the desired lift thickness. The required placement and spreading operations should be such as to avoid segregation of rock sizes. This is discussed in more detail in the following paragraphs. The type roller, lift thickness, and number of passes will be specified, preferably based on results of test fills.

2. Placement Operations. - When rock is dumped on the fill surface and pushed into place by a bulldozer, the fines are moved into the upper part of the lift, thereby creating a smoother working surface for the compacting equipment. If, however, a layer of fines of such thickness is produced so as to choke the upper part of the lift and prevent distribution of the fines throughout the lift, it may be necessary to specify that the rock be dumped directly in place.

Prior to compaction all oversize rock must be removed. This is usually done with bulldozers, crawler tractors fitted with special "rock rakes," or cranes. Oversize rocks are often pushed into a specified zone in the outer slopes. Excessively large rocks are sometimes hauled off to be dumped elsewhere or they are broken up with a drop weight or explosives and used in the rockfill or riprap zone. Another common way of breaking oversize rock is with hydraulic chisels. Oversize rocks should never be pushed to accumulate along the contact slope of a closure section.

Close inspection is required to ensure that the material does not contain excessive fines. Excessive fines can cause excessive postconstruction settlements when the reservoir is filled. It is difficult to specify a limiting amount of fines in the specifications and, consequently, this is rarely done. However, the design office should provide some guidance to field personnel, based on results of rock test fill studies which will aid in determining when excessive fines are present. The design and construction staff must be alert for material variations that could result in undesirable changes in gradation of the material being brought to the embankment. If this occurs it should be called to the attention of the contractor so a change can be made in quarrying techniques.

3. Compaction. - Current practice is to use smooth steel-wheel vibratory rollers to compact all sound rock fill in comparatively thin lifts and minimal application of water. Vibratory rollers having static weights of 5, 10, and 15 tons have been used to construct rockfill dams.

The lift thickness specified is dependent on the size and type of rock and the type of compaction equipment to be used, and is usually determined from results obtained during construction of a test fill.

10.15C

Generally, the lift thickness specified will be no thicker than 24 inches (60 cm) unless test fills show that adequate compaction can be obtained using thicker lifts. Maximum size rock should not exceed 90 percent of the lift thickness.

Scarification of compacted lift surfaces is not necessary and should not be allowed because it disturbs the compacted mass.

C. Unsound Rock in Rockfill. - In the past, use of soft or unsound rocks has been dictated by availability in large quantities from required excavations. The main concern about these materials is their tendency to weather and soften with time when exposed to air and water within the embankment. However, for dams in which large portions of embankments were composed of unsound rocks, it has been shown that when used in random and semipervious zones, they attained adequate shear strength and experienced no further appreciable breakdown after placement. Where unsound rocks will constitute a significant structural portion of a fill, their properties and the best methods of compaction should be determined by means of a test embankment constructed during design studies.

Some rockfills composed of unsound rocks have been compacted by first rolling the loose lift with a heavy tamping roller equipped with long spike or chisel-type teeth ("shale breaker"), and then compacting the lift with conventional tamping or rubber-tired rollers. A summary of this technique is given in Earth and Earth-Rock Dams [5].

SEMICOMPACTED EARTH FILLS

.16

A. Uses. - Stability berms, spoil berms, channel fillings, and low levees to protect farmlands are often constructed of semicompacted fills.

B. Specifications. - Semicompacted fills are those specified to be compacted by the routing of hauling and spreading equipment over the spread layer. Lift thickness is specified but a range of placement water content is either not specified or a very wide range is permitted.

C. Construction Control. - Inspection of semicompacted fill is usually entirely visual, although a few density tests may be made for record purposes. The primary concern of the inspector is to ensure that the specified lift thickness is not exceeded, that suitable materials are being used, and that hauling and spreading equipment cover the fill uniformly.

10.17

SEQUENCE OF PLACEMENT AND MEASUREMENT OF QUANTITIES

.17

A. Schedule of Construction. - The schedule for construction of an earth or rockfill dam may require stage (or phase) construction. In a wide flat valley, the embankment on one side of the river may be constructed to full height under one contract or contract phase, with subsequent portions constructed during following years. Where foundations are soft, the embankment may be constructed to a specified elevation and further fill placement deferred for a year or more to permit dissipation of foundation pore pressures or to achieve an adequate degree of consolidation. In a narrow steep valley with rock foundations, the entire embankment may have to be completed to a stipulated elevation by a certain date to prevent overtopping during flood season. The construction schedule is developed to make maximum use of available borrow and excavation materials, considering river diversion requirements, foundation conditions, and seasonal weather conditions. The designer is responsible for specifying required phasing, staging, and scheduling to allow for optimum use of available materials and to safely and logically divert the river or contain flooding for protection of the public. The contractor is responsible for constructing the particular stage or section of embankment within the time limits specified and for protection of work accomplished during the contract. The inspection force is responsible for determining that each stage or section is constructed using proper placement sequence. The designer must be aware of any changes in sequence or timing of stages so each can be analyzed for approval or appropriately adjusted. Designers, construction staff, and contractor are all responsible for scheduling and staging so that public safety and protection of property are ensured.

B. Placement Sequence. - It is usually required that the embankment be brought up fairly uniformly over the entire width and length of the section under construction. Interim embankment crests should be crowned slightly to provide surface drainage during wet weather. Specified transverse slopes of interim crests may range from 1 to 5 percent. During periods of dry weather, fill heights of central impervious zones are sometimes allowed to exceed heights of adjacent pervious zones by as much as 5 ft (1.5 m) to permit continuous placement of impervious material. However, special precautions such as sloping the impervious fill material away from the pervious zone are required to keep impervious material out of inclined filter zones. This practice should not be allowed in climates where or during seasons when fast developing storms, such as thunderstorms, are common. The provisions in paragraph .14.G should be strictly followed.

Placing material in a cutoff trench should be accomplished by dumping and spreading the first lift of the downstream filter zone material (if such a filter is required at the downstream trench slope) and then dumping and spreading the first lift of impervious material. This should be followed by compaction of both zones concurrently, with separate equipment being used on each zone. Dumping and spreading filter layers first will help to maintain the specified width of the filter zone. A downstream horizontal drainage zone should be completely placed and covered by two lifts of downstream shell materials as soon as possible to prevent contamination of the blanket by exposure to surface waters carrying fines.

10.17C

C. Measurement of Quantities. - Measurement of excavated materials is usually based on cross-section surveys of the area before and after excavation, using the average end area method for computing quantities. For embankment fill, a cross-section survey of the outer boundaries and average end area method are used to compute quantities. For separate zones within an embankment, theoretical quantities are computed from the lines and grades shown on construction drawings. Lines and grades to be used for computing quantities should be clearly specified and shown on construction drawings so that instances of overexcavation or fill placement outside contract lines are easily discernable by the construction staff. This will assist in preventing possible errors in measurement and certification of payment for quantities in excess of contract provisions.

SLOPE PROTECTION

.18

A. Areas to be Protected. - Slope protection is required to protect upstream slopes against damage from wave erosion, weathering, ice, floating debris, and surface erosion. Upstream slope protection of earth dams usually consists of riprap, although soil cement, concrete paving, and asphalt paving have occasionally been used when riprap was not economically justified. Dams with outer shells of sound, durable, large rock may not require further protection. Downstream slope protection is required to protect against damage from surface erosion by wind and rain. Downstream slope protection includes gravel for dry climates, turf in humid climates, riprap where tailwater may create wave action, or waste rock. Proper field construction procedures and enforcement of specifications are particularly important in obtaining slope protection that will remain in place and require minimum maintenance during the life of the dam.

B. Upstream Slope Protection. - Placement of upstream slope protection may be accomplished either as the embankment is being built or after the embankment is completed. This depends on elevation limits of slope protection, the schedule for impounding reservoir water, and the type of slope protection. The best procedure is to require that slope protection construction not lag behind earthfill construction more than 10 ft (3 m) in elevation.

1. Riprap. - Riprap is the most commonly specified type of upstream slope protection. Design Standard No. 13 - EMBANKMENT DAMS, Chapter 7 - *Riprap Slope Protection* presents detailed requirements for the design and construction of riprap slope protection. Properly graded riprap, placed to provide a well-integrated mass with minimum void spaces so that underlying bedding cannot be washed out, provides excellent slope protection. Some primary factors that govern successful construction are:

- Loading from the quarry to provide a good mixture of different sizes within the required gradation in each load. Proper loading from the quarry requires that blasting operations produce proper rock sizes and that loading operations are properly inspected.

10.18B

• Placing loads on the slope should be performed in such a manner so as to provide a uniform distribution of different sizes without segregation and rearrangement of individual rocks in order to provide a rock mass without large voids. A gradation test (performed by weighing a sufficient quantity) should be made for each 10,000 yd^3 (7650 m^3) of placed riprap. Placement should be accomplished by placing loads along the slope against previously placed riprap; this will reduce segregation of sizes that would otherwise occur if loads were dumped in separated piles. A good method of placement to avoid segregation is to use a skip as shown in figure 10.12. Dumping rock at the top of the slope into a chute should never be allowed because this will result in segregation. If dumping is done from trucks it is usually necessary to winch load haulers down the slope to the placement location. Dumping should proceed along horizontal rows and progress up the slope; loads should not be dumped to form rows up the slope. If very large (4 to 5 ft (1.2 to 1.5 m) in diameter) rock is specified, a crane with an orange peel attachment operating from a platform built on the slope can be used. In recent years, backhoes in the 1.5- to 2.5-yd^3 capacity range have become the most common equipment for placing riprap. Good operators can do an excellent job. The riprap must be placed as the embankment is placed because the riprap can only lag about 15 ft (4-5 m) below the top of the fill when backhoes are used. Other equipment, such as Grade Alls, cranes with clamshell buckets, and rubber-tired front-end loaders, can be used to place riprap.

These equipments are preferable to dumping from haulers. Close visual inspection is required after dumping and spreading to determine the degree of uniform distribution of different sizes and close-knit arrangement of individual rock pieces. Reworking, generally by hand, will almost always be required; however, reworking can be kept to a minimum if care is taken when loading to ensure that each individual load has the proper amount of each size rock (i.e., the proper gradation). Supplemental gradation checks might be made by the photogrid method in which a 10- by 10-ft (3- by 3-m) aluminum pipe form containing a 1- by 1-ft grid of rope is placed on the riprap and photographed. From the photograph, the number and size of stones visible at the surface are determined. However, for materials that have been selectively arranged, as by hand, this may not provide an accurate determination of size distribution. Firm enforcement of specifications is required, especially during early stages of riprap placement to ensure a well-graded mass having no large voids.

• A bedding layer or layers designed as a filter between embankment and riprap must be provided between the riprap and embankment material (unless the underlying embankment meets filter criteria with the riprap or, in the cases where the embankment is highly cohesive and non dispersive) to protect the embankment material from eroding by wave action and to provide a stable base for riprap. Placement is shown in figure 10.13.

10.18B

Many riprap failures have occurred because the bedding material was not large enough to preclude being sucked out through riprap interstices by wave action. Removal of the bedding causes settling and dislodgment of overlying riprap, further exposing bedding and embankment material to direct wave action. It is, therefore, necessary that bedding material meet specifications relating to gradation and layer thickness. It is good practice to place rock spalls[4] or crushed stone of like size between the bedding and the riprap if they are available from quarry or required excavation. Use of, and minimum and maximum size of, spalls or equivalent crushed stone should be established in the design memorandum and should be specified if it is appropriate. In some cases, spall material may replace graded bedding material.

Fig. 10.12 - Dragline with Skip Placing Riprap [1]

[4] The term spalls as used herein refers to the finer materials resulting from rock excavation for materials such as riprap. Spalls must be durable fragments of rock, free of clay, silt, sand, or other debris. The gradation of spalls will vary and must be specified for each particular job.

Fig. 10.13 - Gradall Used to Place Riprap Bedding [1]

2. Soil Cement. - Soil-cement slope protection has been used on several USBR dams. Design Standard No. 13 - EMBANKMENT DAMS, Chapter 17, presents detailed requirements for design and construction of soil-cement slope protection. Plant-mixed soil cement is usually spread in 6-in (15-cm) horizontal lifts along the slope in a strip, 7 to 10 ft wide (depending on the slope angle and specified thickness perpendicular to the slope), and compacted by sheepsfoot or rubber-tired rollers. Succeeding lifts are stairstepped up the slope. Control of cement content, water content, and uniformity of mixture are required, as well as density tests and measurement of both lift thickness and lift width. Bonding of compacted layers is important, and scarifying is usually specified on surfaces of compacted layers prior to placing the next lift. Curing is important, and in dry climates, special measures may be needed to prevent drying of compacted layer surfaces.

3. Other Upstream Protection. - Monolithic concrete, hand-placed riprap paving (grouted and ungrouted), and asphalt paving are other methods of protection for upstream slopes. These methods have been used infrequently by Reclamation.

C. Downstream Slope Protection

1. Grass Turf. - Grass turf is usually specified for protection of downstream slopes of earth embankments in humid climates. Where the downstream embankment zone is composed of pervious material, sufficient fine-grained soil or topsoil must be placed to support vegetation growth. The method usually specified consists of clearing the slope of any roots and stones, tilling to a depth of at least 4 in (10 cm), fertilizing, seeding or sprigging, compacting, watering, and maintaining as required to establish the turf. Temporary or permanent protection should be established on completed portions of the embankment as soon as possible. The usual practice of waiting until near the end of construction and trimming slopes by filling erosion channels with loose material and then fertilizing and seeding has resulted in continuing maintenance problems at several projects.

2. Riprap. - Riprap placed on the lower downstream slope to protect against wave action from tailwater should be controlled in the same manner as upstream riprap.

3. Gravel, Cobbles, or Spalls. - Gravel, cobbles, or rock spalls (depending on available material) are sometimes used for downstream slope protection. Where the outer downstream shell contains random granular materials, it is often specified that cobbles and rocks be pushed out to the edge and used in the slope protection. In this case, it is desirable that placement of downstream slope protection be kept 5 to 10 ft (1.5 to 3 m) behind embankment placement. The gravel, cobbles, or spalls are usually dumped and spread horizontally along the outer slope to depths of at least 1 ft (30 cm) measured perpendicular to the surface. If the downstream embankment is erodible, i.e., cohesionless sands, bedding may be required to prevent erosion. The bedding should be designed as a filter between embankment and spalls. An aesthetically pleasing surface can be obtained by placing and/or fine grading the material with a backhoe.

APP.

APPENDIX A - BIBLIOGRAPHY

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